Identifying and Assessing Key Weather-Related Parameters and Their Impacts on Traffic Operations Using Simulation

Prepared by:

ITT Industries Inc.

Systems Division

P.O. Box 15012

Colorado Springs, CO 80935-15012

Federal Highway Administration

Office of Operations R&D

TFHRC, 6300 Georgetown Pike

McLean, VA 222101-2296

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Executive Summary

Adverse weather conditions can have a dramatic impact on the operations and quality of traffic flow. With the advent of advanced traffic management systems (ATMS), there is an opportunity to develop traffic management strategies that seek to minimize the negative weather-related impacts on traffic operations. Although simulation models are widely used in the evaluation of various traffic management strategies, its application to evaluate ATMS strategies under adverse weather conditions needs to be explored.

The objectives of this study were to identify how weather events impact traffic operations, assess the sensitivity of weather-related traffic parameters in the CORridor SIMulation (CORSIM) traffic microsimulation model, develop guidelines for using the CORSIM model to account for the impacts of adverse weather conditions on traffic operations, and identify gaps and recommend future research related to CORSIM's ability to model weather events.

This final report summarizes the methodologies, findings, and conclusions for each of these study objectives. A high-level conclusion from this project is that CORSIM can adequately be used to model the impacts of weather events on traffic operations. This conclusion is based on the fact that a majority of the generic weather-related parameters identified are currently available in CORSIM, and that the key weather-related parameters are adequately sensitive in producing model outputs in-line with that expected from adverse weather.

This report is organized into seven major sections. A summary of each section is provided below.

Section 1 - Introduction

This section presents the background and motivation for completing this project. This section also highlights the objectives of the study and work tasks for each phase of the study.

Section 2 - General Relationship Between Weather Events and Traffic Operations

Conceptually, it is easy to understand that a major weather event, such as a snowstorm, will lead to lower average speeds and higher delays. However, it is important to understand what this relationship is, or in other words, what causes a weather event to degrade traffic operations.

This section shows that a weather event impacts traffic operations through a chain reaction: a weather event causes a change in the roadway environment (e.g., reduced visibility and pavement friction), which causes a reduction in traffic parameters (e.g., lower free flow speeds and capacities), thereby creating a degradation in traffic flow (e.g., higher delays and lower average speeds).

The qualitative impacts of weather events are easily seen through this relationship, but the quantitative impacts have been historically difficult to measure for a number of reasons. For example, there are many "shades" of the severity of a weather event and the impacts are different regionally (i.e., a snowstorm in Florida will have more impact than the same storm in Minnesota) and by time of year (i.e., a snowstorm at the beginning of winter will likely have more impact than the same storm near the end of winter after drivers have acclimated to the adverse weather).

Section 3 – Literature Review

This section summarizes past research regarding the impact of weather events on traffic parameters, or inputs to a traffic model. Past research has quantitatively shown a link between

various weather events and reduced free flow speeds, saturation (discharge) headway, start-up lost time, and traffic demand.

Section 4 - Identifying Simulation Parameters Affected by Weather Events

This section identifies the range of simulation parameters likely impacted by weather events. First, a list of generic microsimulation parameters was developed that are included in most simulation models. Then, those parameters that are potentially impacted by weather events, through a change in the roadway environment, were determined based on the literature review and engineering judgment (e.g., adverse weather generally causes more conservative driver behavior, which means car following behavior is likely impacted by adverse weather).

Section 5 – CORSIM Sensitivity Analysis

The purpose of the sensitivity study was to identify the most sensitive weather-related parameters in CORSIM. Each test parameter was modeled on various geometric networks and congestion (volume) levels using the default value and then changing the value to represent incrementally more conservative driver behavior, as would occur under adverse weather. The MOEs produced by the default value were then compared to the MOEs produced with the changed parameter values to determine the level of sensitivity the parameter has on the MOEs.

Due to the large number of roadway networks, congestion levels, and parameters tested, approximately 45,000 individual CORSIM runs were completed. As a result, a largely automated process of creating the CORSIM input files and summarizing the output files was created specifically for this project.

One interesting result of the sensitivity analysis was a number of parameters tested (19 total) had little or no impact on the MOEs. The majority of these were lane changing parameters. This finding does not mean they have no sensitivity whatsoever, but that they showed no sensitivity to the aggregate-level MOEs used for this study.

A number of weather-related parameters had an expected effect on the MOEs and were categorized as either having a medium or high effect on the MOEs (relative to the other parameters). These parameters are important because they represent the key weather-related parameters that should be altered when trying to model weather events in CORSIM. These parameters included the Car Following Sensitivity Multiplier and Mean Free Flow Speed for FRESIM and Time to React to Sudden Deceleration of Lead Vehicle, Mean Free Flow Speed, Mean Discharge Headway, and Mean Start-Up Delay in NETSIM.

Section 6 – Guidelines for Modeling Weather Events in CORSIM

This section provides practical guidelines for modeling weather events in CORSIM. The guidelines are based on *Guidelines for Applying Traffic Microsimulation Modeling Software* (*18*), a FHWA guidance document on the proper development and application of microsimulation models. The guidance in this section builds on the more general microsimulation guidance by providing additional considerations when modeling weather events in CORSIM. For example, the type, severity, extent, and time period of the weather event being modeled should be agreed upon before coding the model.

This section also details specific CORSIM parameters to consider changing when modeling various weather events. Finally, this section describes an alternate method of calibrating a weather-event model when field data collection during adverse weather is not possible.

Section 7 – Future Research – Modeling Improvement and Case Studies

This section discusses the gaps in the ability for CORSIM to correctly model weather events and future research needs to fill these gaps and further enhance CORSIM's ability to model adverse weather. First, future research is highlighted in the area of modeling driving behaviors under adverse weather condition. A proposed architecture for a weather and traffic data collection system is described that is portable and low in cost. Also, a set of proposed CORSIM adverse weather condition case studies are provided. Based on these cases, weather-responsive traffic signal control strategies can be showcased. Finally, a set of proposed traffic engineer utilities for modeling adverse weather conditions using CORSIM are described in this section.

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1 Introduction

1.1 Background

Adverse weather conditions can have a dramatic impact on the operations and quality of traffic flow. For example, icy pavement conditions can affect the acceleration and deceleration capabilities of vehicles. Reduced visibility can cause drivers to alter their desired speed, how they change lanes, and how they follow other vehicles. Major weather events can cause drivers to modify their travel patterns, such as taking a different route to a destination, leaving for a destination at a different time than normal, or canceling a trip altogether.

With the advent of advanced traffic management systems (ATMS), there is an opportunity to develop traffic management strategies that seek to minimize the negative weather-related impacts on traffic operations. For instance, a weather event that reduces the average operating speeds on an arterial can be mitigated by quickly implementing traffic signal plans that account for the lower speeds while still maintaining progression through a network. However, in order to develop and implement strategies that minimize the effects of adverse weather conditions, a more complete knowledge of how weather events affect traffic operations and how to assess the weather-related effects for a given scenario is needed.

Currently, the relationship between weather events and traffic operations is moderately understood, but only at a macroscopic analysis level, such as the methodologies presented in the Highway Capacity Manual (HCM) (*1*)[1]. Using an HCM-style analysis is in fact one way to model weather impacts in order to develop weather-responsive traffic management strategies. However, a more detailed and potentially more accurate method is to use a microscopic traffic simulation model. A microscopic simulation tool can model individual vehicles on a roadway network, typically on a second-by-second basis or less. Simulation models have the benefit of being able to model complex roadway geometries, traffic control devices, and vehicle configurations that are beyond the limitations of a macroscopic HCM-style analysis.

However, modeling microscopic driver behavior is difficult under ideal weather conditions, let alone under adverse weather conditions. Little research has been conducted on how weather events impact driver behavior logic such as lane changing and vehicle following, both of which are crucial to the accuracy of a microscopic traffic simulation model. In addition, there are a vast number of user-input parameters within simulation models that can be changed. Knowing which key parameters, within a simulation model, should be changed, under various weather conditions, would greatly aid in the development of weather-responsive traffic management strategies.

1.2 Study Objective

The objectives of this study are to identify how weather events impact traffic operations, assess the sensitivity of weather-related traffic parameters in the CORridor SIMulation (CORSIM) traffic simulation model, and develop guidelines for using the CORSIM model to account for the

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[1] HCM does not specifically address the impacts of weather events on highway capacity and quality of service: however, the parameters in the HCM could be user-adjusted to reflect the impacts of weather events.

impacts of adverse weather conditions on traffic operations. More specifically, this study is tasked to do the following:

- Research the relationship between weather events and traffic operations.

- Identify which types of simulation parameters could be affected by weather events.

- Conduct a sensitivity analysis on selected CORSIM simulation parameters to identify the key weather-related parameters that most affect traffic operations.

- Develop basic guidelines on how weather events can be modeled using CORSIM.

- Identify gaps in the CORSIM model regarding modeling weather events.

- Recommend key parameters needing further research to quantify the proper values under adverse weather events.

This study does not recommend specific values (e.g., free flow speed of 35 mi/hr) to be used for each parameter under various weather conditions: rather, it focuses on identifying the general sensitivity of a parameter to traffic operation measures of effectiveness (i.e., average speed). This information may then be used to develop guidelines on how CORSIM can be used to model weather events. It will also be used to determine which parameters need further research, such as field testing or modification of how they are currently used in the CORSIM model.

1.3 Study Approach

This study, which began in September 2002, was conducted on a task-order basis with a total of five tasks. Figure 1 shows a flow chart of the task breakdown and workflow. As shown in Figure 1, the tasks were completed in consecutive order, as the output from one task was required for the next task. This report provides the results for each of these tasks.

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│        │   Develop Work Plan,    │         │      Task A –         │     │
│        │  Deliverables, Schedule,│         │  Project Management   │     │
│        │      and Staffing       │         │                       │     │
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│            │  Conduct Literature  │        │      Task B –         │     │
│            │       Review         │        │   Weather Impacts     │     │
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│  │ Investigate General      │     │  Review Past Research on      │       │
│  │ Relationship between     │     │  Weather Impacts on Traffic   │       │
│  │ Weather Events and       │     │  Operations                   │       │
│  │ Traffic Operations       │     │                               │       │
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│          │ Identify Simulation      │     │      Task C –         │      │
│          │ Parameters Possibly      │     │ Identification of     │      │
│          │ Affected by Weather      │     │    Parameters         │      │
│          │ Events                   │     │                       │      │
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│          │ Develop Automated        │     │      Task D –         │      │
│          │ Procedure for Generating │     │ Sensitivity Analysis  │      │
│          │ and Summarizing CORSIM   │     │                       │      │
│          │ Runs                     │     │                       │      │
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│  │ Determine Which CORSIM   │     │  Code Test Networks and       │       │
│  │ Parameters to Include in │     │  Volume Scenarios             │       │
│  │ Sensitivity Test         │     │                               │       │
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│          │ Execute Sensitivity Test │                                    │
│          │ Runs and Summarize       │                                    │
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│  │ Develop Guidance on      │     │  Identify Weather-Related     │       │
│  │ Using CORSIM to Model    │     │  Gaps in CORSIM and Future    │       │
│  │ Weather Events           │     │  Research Needs               │       │
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│        │ Incorporate All          │       │      Task E –         │      │
│        │ Deliverables and FHWA    │       │   Final Report        │      │
│        │ Comments into Final      │       │                       │      │
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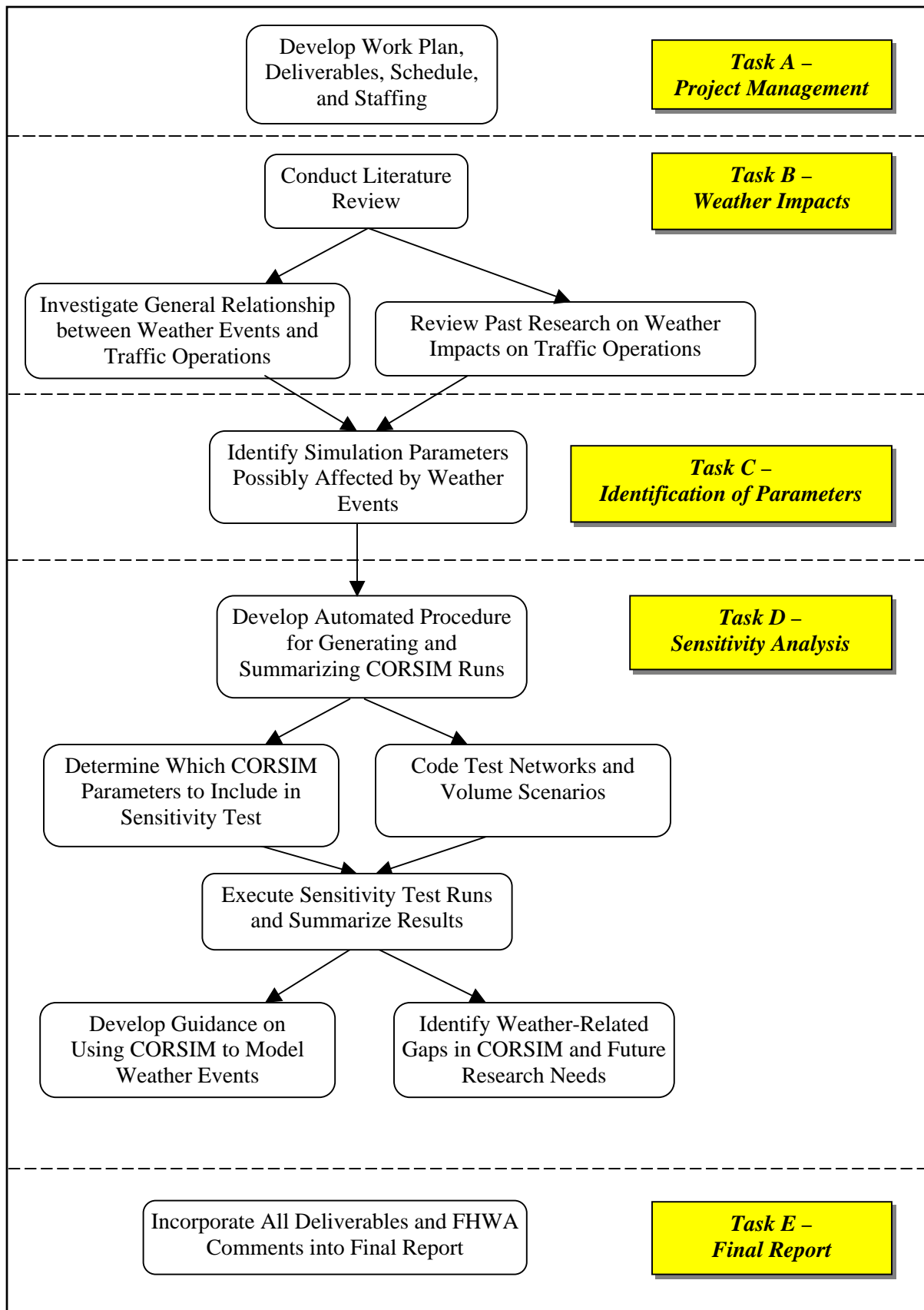
Figure 1. Study Approach.

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1.4 Report Outline

This report represents the final task (Task E in Figure 1) for the "Identifying and Assessing Key Weather-Related Parameters and Their Impacts on Traffic Operations Using Simulation" project. This report is separated into the following sections:

- **Section 1** discusses the objective and approach of the project, including a background discussion on the need for the study.

- **Section 2** discusses the general relationship between weather events and traffic operations, including a discussion of how a change in weather leads to a change in the quality of traffic flow.

- **Section 3** discusses the results of a literature search on field studies of the effects of adverse weather on traffic operations parameters.

- **Section 4** identifies which simulation parameters are potentially sensitive to weather events.

- **Section 5** describes the study methodology and results of the CORSIM sensitivity study of the key weather-related parameters identified in Section 4.

- **Section 6** develops guidelines for modeling weather events using CORSIM.

- **Section 7** proposes future research, modeling improvements, and case studies that could further enhance the ability to model weather events using microsimulation.

- **Section 8** lists the report references.

2 General Relationship Between Weather Events and Traffic Operations

Conceptually, it is easy to understand that a major weather event, such as a snowstorm, will lead to lower average speeds and higher delays. However, it is important to understand what this relationship is, or in other words, what causes a weather event to degrade traffic operations.

Figure 2 shows the general relationship between weather events and the resulting impact on traffic operations. This relationship is similar to that shown by Pisano and Goodwin (*2*), with the exception that the definition of "traffic operations" has been divided into two subparts: traffic parameters (or characteristics) and quality of traffic flow. Traffic parameters are quantitative values that are typically used as inputs to a traffic analysis model. These parameters account for how drivers and their vehicles interact and respond to the roadway network, including the response to other vehicles, traffic control devices, roadway geometry, weather, and other environmental conditions. The quality of traffic flow is the output from a traffic analysis model and is calculated using measures of effectiveness (MOEs). MOEs measure the overall performance of the transportation system, which is directly related to how well drivers and their vehicles respond to the surrounding factors (traffic parameters). Common MOEs include average speed, average density, average delay per vehicle, and number of stops.
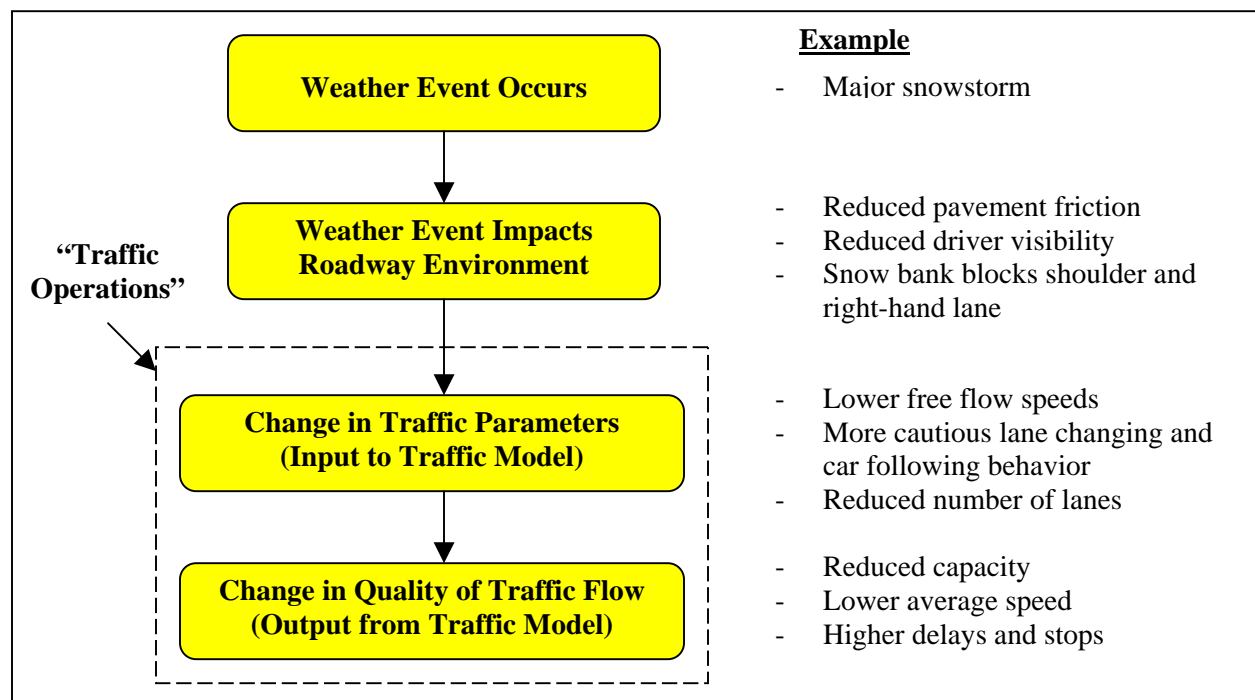
Figure 2. Relationship between Weather Events and Traffic Operations.

This distinction between the input and output in "traffic operations" is important because traffic analysts need to know, for a certain weather event, which traffic parameters to change and how much to change them when inputting them into a traffic analysis model. These changes will produce a new quality of traffic flow reflecting the impacts of the weather event.

2.1 Definition of Weather Event

Weather events are any meteorological occurrence that causes weather conditions to degrade from the "ideal" weather condition. The ideal weather condition is defined as having the following conditions:

- No precipitation.
- Dry roadway.
- Good visibility (greater than ¼ mile).
- Winds less than 10 mi/hr (*3*).

Weather events can change quickly in severity and in coverage area. These changes over time and space present a challenge in modeling weather events in a traffic analysis model. The range of possible weather events that are addressed in this study include: rain, snow, sleet, hail, flooding, fog, ice, sun glare, lightning, dust, wind, and extreme temperatures.

2.2 Relationship Between Roadway Environment and Weather Event

Weather events cause a change in the "roadway environment", a term used by Pisano and Goodwin (*2*), meaning a physical change in the roadway, or roadway devices, or a change on the immediate environment surrounding the roadway including driver, and vehicle changes. Each weather event impacts the roadway environment in a different way. Figure 3 shows the connection between weather events and the roadway environment. As shown in the figure, various weather events, such as fog, dust, rain, snow, sleet, hail, and sun glare, can reduce driver visibility.

Weather Events		Impact on Roadway Environment
Fog, Dust, Rain, Snow, Sleet, Hail, Sun Glare	➤	Reduces Driver Visibility
Ice, Rain, Snow, Sleet, Hail, Flooding	➤	Blocks Lanes or Covers Signs and Pavement Markings Reduces Pavement Friction (Note that reducing pavement friction leads to a reduction in vehicle maneuverability)
Wind	➤	Reduces Vehicle Maneuverability and Stability
Extreme Temperatures, Lightning, Wind	➤	Fails Traffic Control Devices and Communications

Figure 3. Impacts of Weather Events on Roadway Environment.

2.3 Relationship Between Roadway Environment and Traffic Parameters

As the roadway environment changes, resulting changes in traffic parameters will occur. For example, a reduction in driver visibility will logically cause most drivers to drive more cautiously to some degree. This changed driver behavior is reflected in simulation traffic parameters, such as lower free flow speeds and more cautious lane changing and car following

parameters. Traffic parameters represent values that a traffic engineer can control in a simulation model. The ability to modify these parameters in a simulation model provides the means for simulating the impacts of adverse weather conditions. The challenge with microscopic simulation models like CORSIM is that they require many more input traffic parameters than a macroscopic HCM-style model due to the complex modeling of driver behavior on an individual vehicle basis.

Before tracing which traffic parameters are impacted by a change in the roadway environment, it is important to understand the full range of parameters available in a microscopic simulation model. Table 1 displays a generic list of possible traffic parameters in a microscopic simulation model. The parameters are considered generic because they are not specific to any one model and the majority of them are included in most simulation models currently available. However, each model uses slightly different terminology to define these parameters. Therefore, the parameters listed in Table 1 may only be a subset of the actual simulation models parameters. For example, there are more than 20 parameters in CORSIM that are used to model lane changing behavior.

Tracing which traffic parameters are likely affected by weather events (through a change in the roadway environment) was performed based on a review of Table 1, the literature review (Section 3), and engineering judgment. The results of this analysis are presented in Section 4 after the literature review section.

Table 1. Range of Generic Traffic Simulation Parameters.

Category	Parameters
Road Geometry	Pavement condition (wet, dry, etc.) Number of lanes Lane width Lane taper length Segment link length Shoulder type/width Grade Horizontal & vertical curvature Super-elevation

Traffic Control & Management	Traffic signal
	    - Controller type
	    - Green splits, clearance intervals
	    - Progression settings
	    - Actuated settings (detectors, vehicle extension time, etc.)
	Ramp meter
	Regulatory signs (Stop, Yield, Speed Limit, etc.)
	Warning signs (Lane Ends, Merge Ahead, etc.)
	Traveler information signs (VMS, route guidance signs, etc.)
	Surveillance detectors (type and location)
	Lane use by movement (turn only, through only, shared through-turn)
	Lane use by vehicle type (HOV, transit only, no trucks, etc.)
	On-street parking

Driver Behavior	Car following Lane changing Free flow speed Discharge headway Start-up lost time Queue separation/spacing Gap acceptance at intersections Turning speed Rubbernecking (response to incidents) Response to yellow interval Illegal maneuvers
Events/Scenarios	Incidents/Blockages (severity, duration) Incident management (response, emergency vehicle dispatch, etc.) Work zones
Vehicle Performance	Vehicle type distribution (% trucks, buses, etc.) Acceleration/deceleration capability (stopping distance) Turning radius Vehicle length
Simulation Run Control	Length of simulation run Selected output MOEs (reports, animation files, etc.) Resolution of simulation results (temporal and spatial resolution)

Traffic Demand	Vehicle demand (including changes over time), expressed as:
	    - Entry demands and turning percentages
	    - Origin-Destination demands
	Route Choice

Multi-Modal Operations	Transit operations (routes, stops, headways, dwell times, etc.) Bicycle operations (volumes, free flow speeds, shared/exclusive paths, etc.) Pedestrian operations (volumes, walking speeds, priority rules, sidewalk characteristics, etc.)

3 Literature Review

Past research on the simulation of traffic operations under adverse weather conditions can be organized into two main groups: those focusing on the link between weather events and traffic parameters (i.e., heavy rain reduces free flow speeds by 30 percent), and those focusing on the link between weather events and the quality of traffic flow (i.e., heavy rain increases delays by 40 percent.) This review focuses on the former, as knowing the impact of weather events on traffic parameters is the key to using micro-simulation to model weather events.

Very little research focusing on the roadway environment impacts shown in Figure 3 were found. This lack of information is probably due to the difficulty in understanding why motorists respond to a weather event (i.e., is a reduction in free-flow speed really due to a reduction in pavement friction or reduction in visibility?) The literature review yielded information on the impacts of weather events on the following traffic parameters: free flow speed, start-up lost time, saturation headway, and traffic demand.

3.1 Free Flow Speed

A number of studies have shown that adverse weather events reduce the mean free-flow speed, which is defined as the desired speed of drivers in low volume conditions and in the absence of traffic control devices (*1*). The amount of reduction in free flow speed is directly related to the severity of the weather event. Kyte, *et al.*, (*3*) studied the free flow speed on a rural freeway during wet and snow-covered pavement, high wind (greater than 24 km/h), and low visibility conditions (less than 0.28 km). They found the free flow speed reduced by approximately:

- 10 km/h (8 percent) during wet pavement,
- 16 km/h (13 percent) during snow-covered pavement,
- 17 km/h (14 percent) during high wind,
- 18 km/h (15 percent) during low visibility, and
- 35 to 45 km/h (30 to 38 percent) during a combination of snow-covered pavement, low visibility, and high wind.

May (*4*) showed that the free-flow speed on freeways was reduced by approximately:

- 8 percent under light rain or snow,
- 17 percent under heavy rain, and
- up to 40 percent under heavy snow.

Lamm, *et al.*, (*5*) based on a study of two-lane rural highways, found that drivers do not adjust their speeds much under light rain or wet pavement, but they do when visibility becomes obstructed, such as during a heavy rain.

On a sample of freeways in Canada, Ibrahim and Hall (*6*) also found that free flow speed is noticeably decreased during heavy rain and snow, with heavy snow (up to 50 km/h reduction) having a much greater effect than heavy rain (up to 10 km/h reduction).

Perrin, *et al.*, (*7*) measured free flow speed reductions at two signalized intersections on an arterial in Salt Lake City, Utah of:

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- 10 percent on wet pavement,

- 25 percent on wet and slushy pavement, and

- 30 percent on pavement with slushy wheel paths.

Other studies have shown a reduction in average speed on arterials (*8-9*). Average speed, a typical MOE used by traffic engineers, is a different value than free flow speed; average speed takes into account the effects of signal timing and other effects related to the interaction with other vehicles.

3.2   Start-Up Lost Time

Start-up lost time is defined as the additional time consumed by the first few vehicles in a queue at a signalized intersection beyond the saturation headway (*1*). This additional time is due to the time to react to the start of the green phase and for the vehicle to accelerate from a stopped position. Under ideal conditions, the HCM recommends using 2.0 seconds for start-up lost time.

Maki (*8*) measured an increase in start-up lost time of 50 percent, from 2.0 seconds during "normal" conditions to 3.0 seconds under adverse weather conditions, which was defined as being a storm with accumulation of 3 or more inches of snow, on a signalized expressway in the Minneapolis/St. Paul, Minnesota area.

Perrin, *et al.*, (*7*) measured a start-up lost time increase of approximately 25 percent, from 2.0 to 2.5 seconds, under severe snow-related conditions. But only a small difference, from 2.0 to 2.1 seconds, was measured during rain-related conditions.

3.3   Saturation Headway

Saturation headway, or discharge headway, is defined as the average headway between vehicles occurring after the fourth vehicle in a signalized intersection queue and continuing until the last vehicle in the initial queue clears the intersection (*1*). Saturation headway (sec/veh) is the inverse of saturation flow rate (veh/sec or veh/hr). For example, a 10 percent increase in saturation headway equates to a 10 percent decrease in saturation flow rate. The HCM recommends an ideal discharge headway of 1.9 seconds (equates to a saturation flow rate of 1900 passenger cars/hr/lane). This value is then reduced based on adjustments for lane width, heavy vehicles, grade, adjacent parking, bus blockage, area type, lane utilization, right and left turns, pedestrians, and bicyclists.

Perrin, *et al.*, (*7*) measured an average reduction in saturation flow rate of between 6 and 20 percent, increasing with weather severity (snow packed on the street surface being the highest severity).

Maki (*8*) found a saturation flow rate reduction of approximately 10 percent, from 1800 to 1600 veh/hr/lane under adverse weather conditions as defined above.

Botha and Kruse (*10*) measured the effect of residual ice and snow on a signalized arterial in Fairbanks, Alaska. Saturation flow rates were found to be approximately 20 percent lower than the ideal HCM-recommended conditions.

3.4 Traffic Demand

Maki (*8*) measured a reduction in traffic volumes of 15 to 30 percent during adverse weather conditions when compared to ideal weather conditions. The reduction in traffic volumes was attributed to various reasons, including shifting work arrivals and departures, and avoidance of discretionary trips. Traffic demand changes are highly dependent on the severity of the weather conditions and the driver's comfort in adverse weather conditions. For example, drivers in Chicago will react differently to a snowstorm than drivers in Miami.

4   Identifying Simulation Parameters Affected by Weather Events

The literature review documented a number of traffic parameters found to be impacted by weather events. However, there are numerous other microsimulation parameters that have not been measured empirically to behave differently during adverse weather. It is important to identify these parameters and include them in the sensitivity study.

Table 2 through Table 6 shows the traffic simulation parameters that are likely impacted by weather events (through a change in the roadway environment). The selection of these parameters was based on the range of simulation parameters identified in Table 1, the literature review, and the use of engineering judgment based on the concept that driver behavior becomes more conservative during adverse weather conditions. Unfortunately, there is currently no empirical research supporting this concept. Therefore, the table only lists the range of potential, not proven, simulation parameters that may be used to model adverse weather conditions in a simulation model. These simulation parameters may be used as a guide for traffic analysts when considering which parameters to adjust when modeling adverse weather.

The remainder of this section discusses how parameters in each major category: road geometry, traffic control and management, vehicle performance, traffic demand, and driver behavior may be impacted by weather events.

4.1   Road Geometry Parameters

Table 2 displays road geometry parameters likely impacted by weather events though a change in the roadway environment. If available in a simulation model, the pavement condition parameter should be modified during a weather event causing a reduction in pavement friction. The traffic analyst should be aware, however, how the pavement condition parameter affects other parameters. For example, changing the pavement condition parameter in FRESIM (the freeway model within CORSIM) causes an automatic reduction in free flow speed for a link in a horizontal curve. Also, a weather event causing a lane or shoulder blockage would alter the number and width of available lanes, length of tapers associated with lane adds and drops, and shoulder width.

Table 2. Road Geometry Traffic Parameters Impacted by Weather Events.

Generic Traffic Simulation Parameter	Weather Events				
	Fog, Dust, Rain, Snow, Sleet, Hail, Sun Glare	Ice, Rain, Snow, Sleet, Hail, Flooding	Wind, Ice, Rain, Snow, Sleet, Hail, Flooding	Ice, Rain, Snow, Sleet, Hail, Flooding	Extreme Temperatures, Lightning, Wind
	Roadway Environment Impact				
	Reduced Visibility	Reduced Pavement Friction	Reduced Vehicle Maneuverability /Stability	Blocked Lanes/ Covered Signs and Pavement Markings	Failed Traffic Control Devices and Communications
Pavement condition		X			
Number of lanes				X	
Lane width				X	
Lane taper length				X	
Shoulder width				X	

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4.2   Traffic Control and Management Parameters

Table 3 displays traffic control and management parameters likely impacted by weather events though a change in the roadway environment. A reduction in visibility would obviously cause difficulty for drivers to see traffic signals or signs. Thus, the parameters related to sight or reaction distance to the traffic signals and signs would need to be altered. Also, a weather event causing a sign blockage would require altering the parameters related to the visibility of, and compliance with, traffic signs. Finally, a weather event causing a power failure and loss of communications, between traffic devices or to a Traffic Management Center, would require altering the traffic signal settings (i.e., change to emergency flash operation), or the removal of functionality of detector devices, including those used at traffic signals, ramp meters, or system-wide surveillance.

Table 3. Traffic Control and Management Parameters Impacted by Weather Events.

Generic Traffic Simulation Parameter	Weather Events				
	Fog, Dust, Rain, Snow, Sleet, Hail, Sun Glare	Ice, Rain, Snow, Sleet, Hail, Flooding	Wind, Ice, Rain, Snow, Sleet, Hail, Flooding	Ice, Rain, Snow, Sleet, Hail, Flooding	Extreme Temperatures, Lightning, Wind
	Roadway Environment Impact				
	Reduced Visibility	Reduced Pavement Friction	Reduced Vehicle Maneuverability /Stability	Blocked Lanes/ Covered Signs and Pavement Markings	Failed Traffic Control Devices and Communications
Traffic signal	X				X
Ramp meter	X				X
Regulatory signs	X			X	
Warning signs	X			X	
Traveler info. Signs	X			X	X
Surveillance detectors					X
On-street parking				X	

4.3   Vehicle Performance Parameters

Table 4 displays vehicle performance parameters likely impacted by weather events though a change in the roadway environment. A reduction in pavement friction could affect the acceleration and deceleration capabilities of vehicles. These parameters relate to the performance of the vehicle only, and not necessarily the behavior of the drivers. The acceleration and deceleration capability of vehicles are typically used in the car following and lane changing logic of a simulation model; therefore, changing these parameters will likely change the way vehicles follow each other and change lanes in a model.

Table 4. Vehicle Performance Traffic Parameters Impacted by Weather Events.

Generic Traffic Simulation Parameter	Weather Events				
	Fog, Dust, Rain, Snow, Sleet, Hail, Sun Glare	Ice, Rain, Snow, Sleet, Hail, Flooding	Wind, Ice, Rain, Snow, Sleet, Hail, Flooding	Ice, Rain, Snow, Sleet, Hail, Flooding	Extreme Temperatures, Lightning, Wind
	Roadway Environment Impact				
	Reduced Visibility	Reduced Pavement Friction	Reduced Vehicle Maneuverability /Stability	Blocked Lanes/ Covered Signs and Pavement Markings	Failed Traffic Control Devices and Communications
Acceleration / Deceleration Capability		X	X		
Turning radius		X	X		

4.4 Traffic Demand Parameters

Table 5 displays traffic demand parameters likely impacted by weather events though a change in the roadway environment. Any weather event causing one or more major roadway environment impacts could cause a change in vehicle demand and route choice. For example, a major snowstorm over an entire city could cause vehicle demand to be reduced on all links, whereas an isolated storm affecting only a small number of roads could result in no change in overall traffic demand, but different route choices as drivers would avoid the impacted roads. Many simulation models allow the input of traffic demands as origin-destination pairs with a traffic assignment procedure (which determines the preferred route for motorists in traveling between their origin and destination) built into the model. For these models, changing the appropriate parameters to reflect the conditions of the snowstorm on the isolated roads would allow the traffic assignment algorithm to automatically predict the change in route choice associated with the snowstorm.

Table 5. Traffic Demand Traffic Parameters Impacted by Weather Events.

Generic Traffic Simulation Parameter	Weather Events				
	Fog, Dust, Rain, Snow, Sleet, Hail, Sun Glare	Ice, Rain, Snow, Sleet, Hail, Flooding	Wind, Ice, Rain, Snow, Sleet, Hail, Flooding	Ice, Rain, Snow, Sleet, Hail, Flooding	Extreme Temperatures, Lightning, Wind
	Roadway Environment Impact				
	Reduced Visibility	Reduced Pavement Friction	Reduced Vehicle Maneuverability /Stability	Blocked Lanes/ Covered Signs and Pavement Markings	Failed Traffic Control Devices and Communications
Vehicle demand	X	X	X	X	X
Route choice	X	X	X	X	X

4.5 Driver Behavior Parameters

Table 6 displays driver behavior parameters likely impacted by weather events though a change in the roadway environment. Many driver behavior parameters are impacted by weather events causing visibility, pavement friction, or vehicle maneuverability reductions. Car following and

lane changing behavior will likely be more cautious during weather events, with the degree of caution dependent on the severity of the weather event. Free flow speed, start-up lost time, and discharge headway have all been documented to degrade during weather events. In addition, intersection-related parameters such as gap acceptance, turning speed, and responses to the yellow interval are also likely impacted by weather events.

Table 6. Driver Behavior Traffic Parameters Impacted by Weather Events.

Generic Traffic Simulation Parameter	Weather Events				
	Fog, Dust, Rain, Snow, Sleet, Hail, Sun Glare	Ice, Rain, Snow, Sleet, Hail, Flooding	Wind, Ice, Rain, Snow, Sleet, Hail, Flooding	Ice, Rain, Snow, Sleet, Hail, Flooding	Extreme Temperatures, Lightning, Wind
	Roadway Environment Impact				
	Reduced Visibility	Reduced Pavement Friction	Reduced Vehicle Maneuverability /Stability	Blocked Lanes/ Covered Signs and Pavement Markings	Failed Traffic Control Devices and Communications
Car following	X	X	X	X	
Lane changing	X	X	X	X	
Free flow speed	X	X	X	X	
Discharge headway	X	X	X	X	
Start-up lost time	X	X	X	X	
Intersection gap acceptance	X	X	X	X	
Turning speed	X	X	X	X	
Response to Yellow Interval	X	X	X	X	

5   CORSIM Sensitivity Analysis

The purpose of the sensitivity analysis was to determine which weather-related traffic parameters have the greatest impact on the quality of traffic flow. Identifying the most sensitive weather-related parameters was needed for the development of the guidelines for using CORSIM in modeling adverse weather conditions, and for the identification of simulation parameters needing further empirical research.

The sensitivity study showed how these parameters impacted the quality of traffic flow. Various geometric configurations and congestion levels were tested to get a complete assessment of the overall sensitivity of a parameter.

The sensitivity study started with a baseline case created using the default values for the parameters. The sensitivity study focused on changing one parameter value at a time, regenerating the MOEs, and comparing the new MOEs to the baseline case.

This method was found to be limiting, but within the scope of this project. A potentially more detailed and realistic sensitivity test would be to change multiple parameter values at a time, to model specific weather events. This method was not within the scope of the project and would result in exponentially increased data processing and analysis efforts. It should be considered for future sensitivity testing efforts.

The sensitivity study was divided into two major groups: sensitivity of parameters on freeway facilities using FRESIM, and sensitivity of parameters on arterial streets using NETSIM.

5.1   FRESIM Analysis Methodology

A number of different geometric scenarios, or networks, were developed to test the sensitivity of the parameters under various roadway configurations using the FRESIM model in CORSIM. For example, a parameter may not show any sensitivity on a basic freeway segment, but show high sensitivity on a short weaving area. The networks developed for the FRESIM sensitivity analysis are shown in Table 7.

All networks were assumed to have ideal conditions as defined in the HCM (*1*), including 12-foot travel lanes, level grade, no horizontal curves, and no heavy trucks. All freeway segments were assumed to have a free flow speed of 70 mi/hr, while all on- and off-ramps were assumed to have a free flow speed of 45 mi/hr. Also, an analysis period of one hour was used for all simulation runs.

Table 7. FRESIM Sensitivity Analysis Networks.

Network Name	Description
1-lane basic segment	1-lane freeway with no on- or off-ramps, 1 mile in length.
2-lane basic segment	Same as the 1-lane basic segment, except with 2 freeway lanes.
3-lane basic segment	Same as the 1-lane basic segment, except with 3 freeway lanes.
2-lane merge area	2-lane freeway with a single on-ramp, with a ramp volume of 500 veh/hr and 750-foot acceleration lane.
3-lane merge area	Same as the 2-lane merge area, except with 3 freeway lanes.
2-lane diverge area	2-lane freeway with a single off-ramp, with an exiting ramp volume of between 300 and 750 veh/hr (fixed at 15% of freeway volume) and 750-foot deceleration lane.
3-lane diverge area	Same as the 2-lane diverge area, except with 3 freeway lanes.
2-lane weave area	2-lane freeway with an on-ramp and off-ramp separated by 1000 feet, on-ramp volume of 500 veh/hr, off-ramp volume of between 375 and 825 veh/hr (fixed at 15% of freeway volume), and single auxiliary lane connecting the on- and off-ramps.
3-lane weave area	Same as the 2-lane weave area, except with 3 freeway lanes.
System	3.2 miles, 3-lane freeway system including 2 merge areas (each with 500-foot acceleration lanes), 1 diverge area (with a 500-foot deceleration lane), and 1 weave area (with a 1000-foot auxiliary lane).

For each roadway network, the sensitivity of four different congestion levels was tested by incrementally increasing the entering volume (or traffic demand) on the freeway. The four congestion levels tested are shown in Table 8.

Table 8. Congestion Levels for FRESIM Sensitivity Analysis.

Congestion Level	Description
Low	1000 veh/hr/lane, equivalent to a V/C ratio of 0.42.
Medium	1500 veh/hr/lane, equivalent to a V/C ratio of 0.63.
High	2000 veh/hr/lane, equivalent to a V/C ratio of 0.83.
Very High	2400 veh/hr/lane, equivalent to a V/C ratio of 1.0.

The HCM estimates the capacity of a basic freeway segment with a free flow speed of 70 mi/hr to be 2400 veh/hr/lane assuming ideal conditions (*1*). In FRESIM, the upper bound of capacity can be limited by using the Minimum Separation for Generation of Vehicles parameter. For the sensitivity tests, this value was fixed at 1.5 seconds (default is 1.6 seconds), which equates to a maximum entering volume of 2400 veh/hr/lane. It should be noted that the capacity can be limited by the driver behavior logic in some cases: this behavior was seen in the sensitivity study as discussed below.

Testing at V/C ratios above 1.0 was not conducted for the freeway sensitivity tests. With values above 1.0 it was impossible to create a congested state, on a basic freeway segment, without creating a downstream bottleneck. Because simple basic and merge/diverge networks were used in this study, any demand volume over capacity would still operate at capacity, while creating

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congested conditions further upstream. Future research into the sensitivity of freeway parameters under over-capacity conditions should be considered, based on the results shown in this study.

The measures of effectiveness (MOEs) used to quantify the effects of parameter changes on the quality of traffic flow are shown in Table 9.

Table 9. FRESIM MOEs for Sensitivity Analysis.

Measure of Effectiveness	Description
Throughput (veh/hr/lane)	Measures the volume of vehicles traveling through a uniform segment. By gradually increasing the entering demand volume, the capacity of the segment was estimated by noting at what point the actual volume no longer matched the entering demand volume. This MOE was used for the basic, merge, diverge, and weave networks. However, it was not used for the system network because there are different segment types within the system and each segment type has a different capacity.
Vehicle-Miles of Travel (veh-mi/hr)	Measures the number of vehicles traveling through a segment or multiple segments while taking into account the length of the segments. This MOE, which is often used for freeway system analyses, was only used for the system network as a surrogate to throughput, as it indirectly measures the capacity of the system while also taking into account the length of the network.
Average Speed (mi/hr)	Measures the average space mean speed over the entire freeway network. This MOE was used on all test networks.
Average Density (veh/mi/lane)	Measures the average density over the entire freeway network. This MOE was used on all test networks.
Average Delay (sec/veh)	Measures the difference in actual travel time and desired travel time (based on the free flow speed). This MOE was used on all test networks.

The MOEs listed in Table 9 were only summarized within the portion of the network that captured the extent of the congestion and experienced the most change in MOEs from one congestion level to the next. Table 10 lists the MOE collection area for each network.

Table 10. FRESIM MOE Collection Areas.

Network Name	MOE Collection Area
1-lane basic segment	Entire 1.0-mile length of the freeway segment.
2-lane basic segment	Same as 1-lane basic segment.
3-lane basic segment	Same as 1-lane basic segment.
2-lane merge area	The length of freeway (including the acceleration lane) beginning with the on-ramp gore area and extending downstream 1500 feet. This distance was used because the HCM states 1500 feet is generally the area of influence at merge and diverge areas, and this was found to be fairly accurate based on visual inspection of the CORSIM animation for the merge area networks.
3-lane merge area	Same as 2-lane merge area.
2-lane diverge area	The 4000-foot length of freeway starting at the off-ramp gore area and extending upstream 4000 feet. The area of influence was increased to 4000 feet because vehicles on the freeway began changing lanes to get in the proper lane 2500 feet upstream of the actual diverge area itself (based on the 2500-foot default off-ramp reaction point parameter), which created congestion between 2500 and approximately 4000 feet upstream of the diverge area.
3-lane diverge area	Same as 2-lane diverge area.
2-lane weave area	The freeway lanes and auxiliary lane within the 1000-foot weave area.
3-lane weave area	Same as 2-lane weave area.
System	The entire 3.2-mile freeway segment, including the auxiliary lanes associated with the on- and off-ramps but not the ramps themselves.

The FRESIM sensitivity study focused on the car following, lane changing, and free flow speed parameters because the other driver behavior parameters shown in Table 6 apply to intersections on surface streets. Also, the majority of the other parameters listed in Table 2 through Table 6 have major impacts on the quality of traffic flow; thus they are already known to be very sensitive parameters. For example, reducing the number of lanes from three to two due to a lane blockage, changing a signal control to emergency flashing due to a power outage, or reducing the traffic demand by 20 percent due to a major snowstorm all have major impacts on the quality of traffic flow. Such events are easily discernable as having a major affect on traffic flow, but the more subtle changes in car following and lane changing behavior are not quite as obvious and thus are the focus of this sensitivity study.

Table 11 through Table 13 display the FRESIM parameters included in the sensitivity analysis. Each parameter was tested at the default value, along with four other values representing incrementally more conservative driver behavior, as would be the case with increasingly severe weather conditions. As a result, the sensitivity tests were "one-sided" in that they only tested values to one side of the default value. However, a few parameters were tested on both sides because it was not clear which side represented the more conservative driver behavior (e.g., Anticipatory Lane Change Distance.)

The car following parameters were tested on the basic segment (1-lane basic segment, 2-lane basic segment, and 3-lane basic segment), and system networks. The basic segment networks were used to isolate the sensitivity of the car following parameters (without the MOEs being influenced by factors associated with merging or diverging), while the system network was used to show the sensitivity within the context of a real-world network consisting of merges, diverges, and weave areas. Table 11 shows car following FRESIM parameters included in the sensitivity analysis.

Table 11. Car Following FRESIM Parameters Included in Sensitivity Analysis.

FRESIM Parameter	Definition
Car Following Sensitivity Factor	This factor is the primary user input in calculating the desired time (in seconds) headway between a leader-follower vehicle pair. A higher value means more space between vehicles. A different value is specified for each driver type (default = 1.25 to 0.35 sec. based on driver type, mean = 0.80 sec.).
Car Following Sensitivity Multiplier	A link-specific multiplier of the car-following sensitivity factor (default = 100%). The multiplier is applied to all driver types and therefore changes the overall mean of the sensitivity factor. This value can be used to calibrate car-following behavior on a link-by-link basis.
Pitt Car Following Constant	The minimum distance between the rear of the lead vehicle and front of the following vehicle, regardless of vehicle speed (default = 10 ft.).
Lag Acceleration/ Deceleration Time	The time delay (due to perception/reaction time) for motorists when starting to accelerate or decelerate (default = 0.3 sec.).
Maximum Non-Emergency Deceleration	The maximum deceleration on level grade and dry pavement in non-emergency conditions (i.e., normal lane changing and car following behavior). Reflects driving habits and not capability of the vehicle (default = 8 ft/sec^2).
Jerk Value	The maximum change in acceleration between consecutive intervals (default = 7 ft/sec^3). A higher value results in more aggressive driver behavior.

The lane changing parameters were tested on all of the networks described in Table 7 with the exception of the basic 1-lane segment network because lane changes are not possible on a 1-lane segment. All other networks test various types of lane change environments, including mandatory lane changes at on- and off-ramps, discretionary lane changes on a basic freeway segment, and anticipatory lane changes upstream of merge areas. Refer to the CORSIM User's Guide (*11*) and Halati, *et al.*, (*12*) for a detailed description of the FRESIM vehicle movement logic. The lane changing FRESIM parameters included in the sensitivity analysis are displayed in Table 12.

Table 12. Lane Changing FRESIM Parameters Included in Sensitivity Analysis.

FRESIM Parameter	Definition
Time to Complete Lane Change	The time to complete a lane change maneuver (default = 2.0 sec). Increasing this value results in more extended, smooth lane changes.
Advantage Threshold for Discretionary Lane Change	Used to calculate the relative advantage in making a discretionary lane change (default = 0.4). The advantage (measured in speed and volume) in changing lanes must be greater than the condition in the current lane by a factor of 0.4. Increasing this value decreases the number of lane changes.
Discretionary Lane Change Multiplier	A multiplier used in calculating the desire for discretionary lane changes (default = 0.5). Increasing this value increases the desire for discretionary lane changes.
Gap Acceptance Parameter	Used to determine the acceptable gap for mandatory lane changes (default = 3). A higher value represents less aggressive driver behavior and fewer lane changes.
Percent Cooperative Drivers	Percentage of drivers desiring to yield the right-of-way to vehicles attempting to merge ahead of them (default = 20%).
Maximum Non-Emergency Deceleration	The maximum deceleration on level grade and dry pavement in non-emergency conditions (i.e., normal lane changing and car following behavior). Reflects driving habits and not capability of the vehicle (default = 8 ft/sec^2).
Maximum Emergency Deceleration	The maximum deceleration on level grade and dry pavement in emergency conditions (i.e., sudden stop to prevent a collision). Reflects driving habits and not capability of the vehicle (default = 15 ft/sec^2).
Leader's Maximum Deceleration as Perceived by Follower	The maximum deceleration of the lead vehicle in an adjacent lane as perceived by a potential lane-changing vehicle, which is used to determine whether a gap in the adjacent lane is acceptable (default = 15 ft/sec^2).
Anticipatory Lane Change Speed	Vehicles upstream of a merge area will change lanes to avoid the area if the speed of the acceleration lane falls below this threshold (default = 2/3 free flow speed).
Anticipatory Lane Change Distance	Vehicles upstream of a merge area begin to react (in terms of a potential lane change to avoid congestion related to the merge area) this distance in advance of the acceleration lane (default = 1500 ft.).

The two free flow speed parameters were tested on all of the test networks. Table 13 shows the free flow speed FRESIM parameters included in the sensitivity analysis.

Table 13. Free Flow Speed FRESIM Parameters Included in Sensitivity Analysis.

FRESIM Parameter	Definition
Mean Free Flow Speed	The desired mean speed of vehicles in the absence of any impedance due to other vehicles or traffic control devices (link specific).
Free Flow Speed Multiplier	A percentage multiplier for each driver type of the mean free flow speed. A more aggressive driver type receives a higher multiplier to represent a higher free flow speed. Together, the multipliers provide a distribution of free flow speed by driver type (default = 88-112% based on driver type).

5.2   NETSIM Analysis Methodology

A number of different geometric scenarios, or networks, were developed to test the sensitivity of the parameters under various roadway configurations using the NETSIM model in CORSIM. The networks developed for the NETSIM sensitivity analysis are shown in Table 14. Figure 4 shows the two intersection networks as viewed in TRAFED, the input editor interface for TSIS.

Table 14. NETSIM Sensitivity Analysis Networks.

Network Name	Description
1-lane basic segment	1-lane arterial segment (no intersections or driveways) of 1-mile in length and free flow speed of 45 mi/hr.
2-lane basic segment	Same as the 1-lane basic segment, except with 2 arterial lanes.
3-lane basic segment	Same as the 1-lane basic segment, except with 3 arterial lanes.
Single suburban intersection	5-lane arterial with free flow speed of 45 mi/hr intersecting a 3-lane collector street with free flow speed of 30 mi/hr. The intersection is controlled by a fully actuated traffic signal with protected left-turn phasing, 250-foot left turn bays on all approaches, and a maximum cycle length of 120 seconds (if all phases max-out). This intersection is typical of those found on major arterials in a suburban setting. Figure 4 displays the suburban intersection in TRAFED (TSIS input editor interface.)
Single urban intersection	3-lane collector intersecting a 2-lane collector, both with free flow speeds of 30 mi/hr. The intersection is controlled by a pre-timed traffic signal with 2-phases (one for each roadway with permitted left-turn phasing), 150-foot left turn bays on all approaches, and a fixed cycle length of 80 seconds. This intersection is typical of those found in urban or downtown settings. Figure 4 displays the urban intersection in TRAFED (TSIS input editor interface.)
System	2.0-mile arterial corridor with 4 traffic signals at 2000-foot spacing. The arterial has a free-flow speed of 45 mi/hr with 2-through lanes in each direction and 250-foot left turn bays at the traffic signals, and the intersecting minor streets are 1 lane in each direction with 250-foot left and right turn bays at the intersections. The traffic signals are controlled by a semi-actuated, coordinated plan with a 120-second cycle.
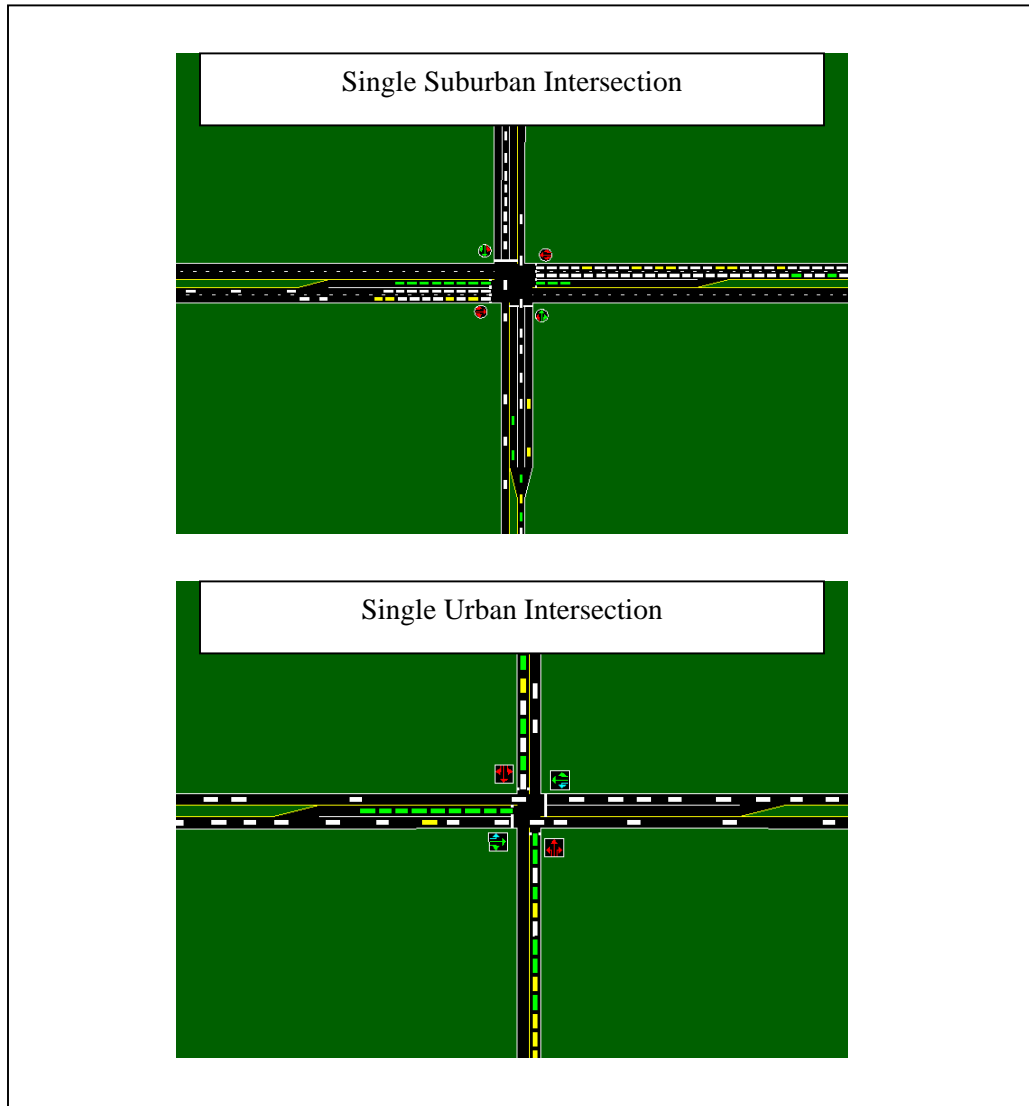
Figure 4. NETSIM Suburban and Urban Intersection Networks.

All networks were assumed to have ideal conditions as defined in the HCM (*1*), which includes 12-foot travel lanes, level grade, no horizontal curves, and no heavy trucks. An analysis period of one hour was used for all simulation runs.

For each test network, the sensitivity to four different congestion levels was tested by incrementally increasing the entering volume (or traffic demand) on the entry links. The four congestion levels tested on the basic 1-, 2-, and 3-lane networks are listed in Table 15.

Table 15. Congestion Levels for NETSIM Sensitivity Analysis.

Congestion Level	Description
Low	800 veh/hr/lane, equivalent to a V/C ratio of 0.4.
Medium	1200 veh/hr/lane, equivalent to a V/C ratio of 0.6.
High	1600 veh/hr/lane, equivalent to a V/C ratio of 0.8.
Very High	2000 veh/hr/lane, equivalent to a V/C ratio of 1.0.

The HCM does not provide guidance on the segment capacity of arterial streets, mainly because the capacity on arterials is determined by traffic signals and not the segment characteristics between traffic signals. However, it is clear that the segment capacity of arterials is generally lower than on freeways due to the lower free flow speeds and increased friction effects (driveway access, on-street parking, narrow lanes, turning vehicles, etc.). Thus, a capacity of 2000 veh/hr/lane was assumed for the basic arterial test networks based on a free flow speed of 45 mi/hr. Even though this is just an estimate, it is important to remember that the purpose of this study is to test relative sensitivity of different parameters and not to determine the absolute value of capacity or other MOEs.

As mentioned previously in the FRESIM analysis methodology, the Minimum Separation for Generation of Vehicles parameter can be used to limit the upper bound of capacity. However, this parameter is not available in NETSIM. As a result, segment volumes as high as 2700 veh/hr/lane on a 1-lane arterial and 2600 veh/hr/lane on a 2-lane arterial, assuming a free flow speed of 45 mi/hr, were achieved in the current version of NETSIM. These values are higher than the capacity of typical freeways and are clearly not realistic for an arterial segment. Based on this, it is recommended that the Minimum Separation for Generation of Vehicles parameter be available in NETSIM with an appropriate default value reflecting a realistic capacity of arterials, such as 1.8 seconds (equivalent to 2000 veh/hr/lane).

For the single suburban intersection, single urban intersection, and system networks, the entering demand volume on all approaches was incrementally increased to achieve V/C ratios of approximately 0.6, 0.8, 1.0, and 1.1. The highest volume scenario was limited to a V/C ratio of 1.1 because ratios higher than 1.1 resulted in queue spillback beyond the limits of the network and, thus, the MOEs would not reflect the extent of the congestion.

Table 16 displays the MOEs used to measure the quality of traffic flow under the various network and volume scenarios for the NETSIM cases.

Table 16. NETSIM MOEs for Sensitivity Analysis.

Measure of Effectiveness	Description
Throughput (veh/hr/lane)	Measures the volume of vehicles traveling through a uniform segment or intersection. By gradually increasing the entering demand volume, the capacity of the segment or intersection can be estimated by noting at what point the actual volume no longer matches the entering demand volume. This MOE was used on the all networks except the system network.
Vehicle-Miles of Travel (veh-mi/hr)	Measures the number of vehicles traveling through a segment or multiple segments while taking into account the length of the segments. This MOE, which is often used for system analyses, was only used for the system network as a surrogate to throughput, as it indirectly measures the capacity of the system when incrementally increasing the entering demand volume until the vehicle-miles of travel no longer increases at a commensurate rate.
Average Speed (mi/hr)	Measures the average space mean speed over the entire network. This MOE was used on the basic and system networks. However, it was not used on the single intersection networks as stopped delay was deemed a more appropriate MOE at an intersection level.
Stopped Delay (sec/veh)	Measures the time spent stopped due to the effects of a traffic signal. This MOE was used on the single suburban and urban intersection networks because it measures the quality of service given by a traffic signal. Control delay was not used here because it is a function of the free flow speed, and free flow speed is a parameter in the sensitivity analysis. Thus, control delay would not give a consistent comparison when testing the free flow speed.
Average Delay (sec/veh)	Measures the difference in actual travel time and desired travel time. This MOE, used on all test networks, takes into account delays due to traffic control devices, and delays due to the interaction with adjacent vehicles.
Number of Lane Changes (lane changes/hr)	Measures the total number of lane changes made on the network. This MOE, used on all test networks, is not a direct measure of the quality of traffic flow, but it was included because it is a helpful measure in understanding why the other MOEs did or did not change significantly and the effects the parameters have on lane changing behavior.

The MOEs listed in Table 16 were only summarized within the portion of the network that captured the extent of the congestion and experienced the most change in MOEs from one congestion level to the next. Table 17 lists the MOE collection area for each network.

The simulation parameters chosen for the arterial sensitivity testing included the car following, lane changing, free flow speed, discharge headway, start-up lost time, and turning speed parameters within NETSIM. As mentioned previously in the FRESIM analysis methodology, the majority of other parameters identified in Section 4 as being impacted by weather events are already known to have a major impacts on the quality of traffic flow and thus were not included in this sensitivity analysis.

Table 17. NETSIM MOE Collection Areas.

Network Name	MOE Collection Area
1-lane basic segment	The entire 1.0-mile length of the segment.
2-lane basic segment	Same as the 1-lane basic segment.
3-lane basic segment	Same as the 1-lane basic segment.
Single suburban intersection	Averaged (weighted based on the approach volume) over all intersection approaches.
Single urban intersection	Averaged (weighted based on the approach volume) over all intersection approaches.
System	Averaged over the major street links only.

Table 18 through 23 display the NETSIM parameters included in the arterial sensitivity analysis. Each parameter was tested at the default value, along with four other values representing incrementally more conservative driver behavior, as would be the case with increasingly severe weather conditions. As a result, the sensitivity tests were "one-sided" in that they only test values to one side of the default value. However, a few parameters were tested on both sides because it was not clear which side represented the more conservative driver behavior.

NETSIM only has one car following parameter, as compared to six in FRESIM. In NETSIM, the impacts of traffic control devices and lane changing maneuvers to prepare for downstream turning movements often control the vehicle movement logic. Thus, a detailed car following logic in NETSIM is not as critical to modeling realistic traffic flow as it is in FRESIM. On the other hand, the lane changing logic in NETSIM is quite detailed, reflected in the fact that there are 15 NETSIM lane changing parameters. Refer to the CORSIM User's Guide (*11*) and Halati, *et al.*, (*12*) for a detailed description of the vehicle movement logic in NETSIM. Table 18 shows the car following NETSIM parameter included in the sensitivity analysis.

Table 18. Car Following NETSIM Parameter Included in Sensitivity Analysis.

NETSIM Parameter	Definition
Time to React to Sudden Deceleration of Lead Vehicle	The amount of time for a driver to begin decelerating after the leader begins a sudden deceleration due to perception/reaction time (default = 1.0 sec).

The lane changing parameters were tested on all the test networks, except the basic one-lane and urban intersection networks (one through lane in each direction) because obviously lane changes are not possible on one-lane roadways. Table 19 shows the lane changing NETSIM parameters included in the sensitivity analysis.

Table 19. Lane Changing NETSIM Parameters Included in Sensitivity Analysis.

NETSIM Parameter	Definition
Driver Type Factor	This factor is used to calculate a driver's "intolerable" speed – the speed below which a driver begins looking for a lane change (default = 25). A higher value means drivers will have a higher intolerable speed and thus will look for lane changes more often.
Urgency Threshold	A driver's desire to change lanes becomes more urgent as he gets closer to the object requiring a lane change (lane drop or slow-moving leader). Once a driver's urgency factor (based on driver aggressiveness and distance to lane-change object) exceeds this factor, then the acceptable deceleration for changing lanes begins decreasing (default = 0.2).
Minimum Deceleration for a Lane Change	A driver's acceptable deceleration (or risk) for lane changes varies depending on his urgency. This value defines the acceptable deceleration when a driver's urgency for changing lanes is very low. Decreasing this value decreases the amount of risk a driver is willing to take and thus decreases the number of lane changes (default = 5 ft/sec^2).
Difference in Minimum /Maximum Deceleration for Mandatory Lane Changes	A driver's acceptable deceleration (or risk) for mandatory lane changes can vary depending on his urgency. This factor, measuring the difference in the min. and max. acceptable decelerations, defines *how much* the acceptable deceleration can vary. The default value (10 ft/sec^2) means the min. and max. acceptable acceleration can vary as much as 10 ft/sec^2.
Difference in Minimum/ Maximum Deceleration for Discretionary Lane Changes	A driver's acceptable deceleration (or risk) for discretionary lane changes can vary depending on his urgency. This factor, measuring the difference in the min. and max. acceptable decelerations, defines *how much* the acceptable deceleration can vary. The default value (5 ft/sec^2) means the min. and max. acceptable acceleration can vary as much as 5 ft/sec^2.
Safety Factor	This factor represents the amount of caution by a lane-changer (default = 0.8). For example, if the min. acceptable deceleration is 10 ft/sec^2, then the acceptable deceleration with the safety factor is 10 x 0.8 = 8 ft/sec^2.
Headway at Which All Vehicles Attempt Lane Change	The headway below which all drivers will attempt a lane change (default = 2.0 sec.). Increasing this value results in drivers attempting fewer lane changes.
Headway at Which No Vehicles Attempt Lane Change	The headway above which no drivers will attempt a lane change (default = 5.0 sec.). Increasing this value results in drivers attempting more lane changes.
Time to React to Sudden Deceleration of Lead Vehicle	This factor is used to calculate a driver's "intolerable" speed – the speed below which a driver begins looking for a lane change (default = 25). A higher value means drivers will have a higher intolerable speed and thus will look for lane changes more often.
Duration of a Lane Change	The time to complete a lane change maneuver (default = 3.0 sec). This is also the minimum time after a lane change is initiated that another lane change can begin. Increasing this value results in more extended, smooth lane changes.
Percent Drivers Who Cooperate With Lane Changer	The percentage of drivers who will slow down to allow a lane change in front of them (default = 50%). Increasing this value results in more lane change opportunities.
Distance Over Which Drivers Perform Lane Change	The mean distance for a driver to contemplate and complete a lane change (default = 300 ft). Higher values result in drivers seeking lane changes over a longer distance and thus make a smoother lane change.

Table 19 (continued).

NETSIM Parameter	Definition
Distribution of Distance to Attempt a Lane Change	A percentage multiplier for each driver type of the mean lane change distance (default ranges from 125-75%).
Deceleration of Lead Vehicle	The max. deceleration rate of a lead vehicle (default = 12 ft/sec^2). A higher value results in fewer acceptable gaps (because followers will require larger gaps) and fewer lane changes.
Deceleration of Following Vehicle	The max. deceleration rate of a following vehicle (default = 12 ft/sec^2). A higher value means followers will accept smaller gaps and thus make more lane changes.

The free flow speed parameters were tested on all the test networks. The two NETSIM free flow speed parameters are the same as those in FRESIM, however the default multipliers are slightly different in each model. Table 20 shows the free flow speed NETSIM parameters included in the sensitivity analysis.

Table 20. Free Flow Speed NETSIM Parameters Included in Sensitivity Analysis.

NETSIM Parameter	Definition
Mean Free Flow Speed	The desired mean speed of vehicles in the absence of any impedance due to other vehicles or traffic control devices (link specific).
Free Flow Speed Multiplier	A percentage multiplier for each driver type of the mean free flow speed. A more aggressive driver type receives a higher multiplier to represent a higher free flow speed. Together, the multipliers provide a distribution of free flow speed by driver type (default = 75-127% based on driver type).

The queue discharge headway, start-up lost time, and turning speed parameters are only applicable at intersections and thus were tested on all the networks except for the basic segment networks. Table 21 through 23 shows the discharge headway, start-up lost time, and turning speed NETSIM parameters included in the sensitivity analysis, respectively.

Table 21. Discharge Headway NETSIM Parameters Included in Sensitivity Analysis.

NETSIM Parameter	Definition
Mean Discharge Headway	The mean headway between vehicles discharging from a standing queue (mean = 1.8 sec).
Discharge Headway Multiplier	A percentage multiplier for each driver type of the mean discharge headway (default ranges from 170-50%).

Table 22. Start-Up Lost Time NETSIM Parameters Included in Sensitivity Analysis.

NETSIM Parameter	Definition
Mean Start-Up Delay	The mean delay (due to perception/reaction time) of the first vehicle in a queue due to a traffic signal (default = 2.0 sec).
Start-Up Lost Time Multiplier	A percentage multiplier for each driver type of the mean start-up delay (ranges from 218-23%).

Table 23 Turning Speed NETSIM Parameters Included in Sensitivity Analysis

NETSIM Parameter	Definition
Maximum Allowable Left Turn Speed	The speed at which vehicles making a left-turn will travel through the turn if unimpeded by other vehicles (default = 22 ft/sec).
Maximum Allowable Right Turn Speed	The speed at which vehicles making a right-turn will travel through the turn if unimpeded by other vehicles (default = 13 ft/sec).

5.3   Data Processing Procedure

Overall, approximately 45,000 individual CORSIM simulation runs were processed for the sensitivity analysis: 25,000 in FRESIM and 20,000 in NETSIM. The need for the large number of runs becomes clear when considering the following for the FRESIM runs:

- **Parameters** - 18 total FRESIM parameters were tested (see Table 2 through Table 6).

- **Parameter values** - each parameter was tested using the default value and four additional values representing incrementally more conservative driver behavior as would be expected under adverse weather.

- **Networks** - each parameter was tested on an average of seven FRESIM networks (car following parameters tested on four networks, lane changing on nine networks, and free flow speed on ten networks) (see Table 7).

- **Congestion level** - each FRESIM network was tested at four different congestion levels (see Table 8).

- **Simulation runs** - Ten simulation runs were performed for each scenario to take into account the stochastic variations of the simulation model.

Therefore, the number of total FRESIM runs equals approximately 25,000 ($18^x 5^x 7^x 4^x 10$).

Due to the large number of simulation runs, the process of creating the CORSIM input files and summarizing the output files was largely automated. The data processing was completed through four steps as described below.

Step 1 – Create the CORSIM input files (TRF files).

A customized script (in both Visual Basic and C++) was created that automatically generated new TRF files by taking a base TRF file and changing one or more parameters at a time. As a result, thousands of TRF files could be created with a single Do Loop command, changing the value of one or more parameters multiple times. A spreadsheet was created with all the desired network-congestion level-parameter value combinations, which was read by the script to create the TRF files.

Step 2 – Run CORSIM ten times for each input file and create an output file summarizing the relevant MOEs from the ten runs.

The multi-run function available in TSIS 5.1 (the simulation environment that includes CORSIM) was used to run CORSIM ten times for each input file. The Output Processor function available in TSIS was also used to create an output file in Excel format summarizing the mean and standard deviations of the MOEs for the ten runs. The random number seeds were changed for each of the ten runs.

Step 3 - Copy all relevant MOE data from the output files into a single database.

Customized Visual Basic macros were created that copied the relevant MOE data from the thousands of output files into two databases, one each for the FRESIM and NETSIM runs. The macros also calculated t-values to test the statistical significance of the results (at a 95% confidence interval).

Step 4 - Create a one-page summary of MOEs for each parameter-network combination

One-page summaries for each parameter-network combination (e.g., sensitivity of the car-following factor on basic two-lane freeway) were created using customized Visual Basic macros that read the values from the database created in Step 3.

The end product of the data processing is a one-page summary for each parameter-network combination (e.g., medium congestion level on basic one-lane network). These one-page summaries provided a great tool for visually evaluating the sensitivity of each parameter. Figure 5 shows a sample one-page summary for the Car Following Sensitivity Multiplier on the FRESIM system network.

Sensitivity of Car Following Sensitivity Multiplier on System Network

General Information

|	
Parameter Name:	Car Following Sensitivity Multiplier
Parameter Type:	Car Following
Test Network:	System
Model:	Fresim
Input Level:	Link
TRAFED Location:	Double-click a link ->"General" tab
Record Type/Field(s):	Record Type 20/Field(s) 17
Default Value:	100
Sensitivity Range:	100, 125, 150, 175, 200
Definition:	A link-specific (can be different for each roadway link) multiplier of the car following sensitivity factor. This value can be used to calibrate car following behavior on a link-by-link basis.

Test Network

Freeway Lanes:	3
Analysis Area Length:	3.2 miles
Freeway Free Flow Speed:	70 mph
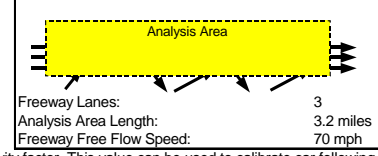
Results

Entering Volume	VEH-MI OF TRAVEL (veh-mi/hr)				
	Car Following Sensitivity Multiplier				
(veh/hr/ln)	100 *	125	150	175	200
1000	11015.7	11019(0%)	11017(0%)	11013(0%)	11013(0%)
1500	15401.7	15391(0%)	15368(0%)	15373(0%)	**14869(-3%)**
2000	19326.1	**18246(-6%)**	**17364(-10%)**	**16197(-16%)**	**14875(-23%)**
2400	19298.5	**18212(-6%)**	**17335(-10%)**	**16178(-16%)**	**14916(-23%)**

Entering Volume	AVERAGE SPEED (mi/hr)				
	Car Following Sensitivity Multiplier				
(veh/hr/ln)	100 *	125	150	175	200
1000	66.7	**66.3(-1%)**	**65.8(-1%)**	**65.2(-2%)**	**64.4(-3%)**
1500	65.2	**64.2(-2%)**	**62.2(-5%)**	**57.2(-12%)**	**38.1(-42%)**
2000	50.3	**41.2(-18%)**	**38.6(-23%)**	**36.1(-28%)**	**33.1(-34%)**
2400	45.2	**41.4(-8%)**	**39(-14%)**	**35.8(-21%)**	**33.5(-26%)**
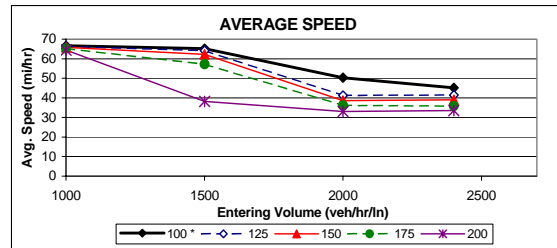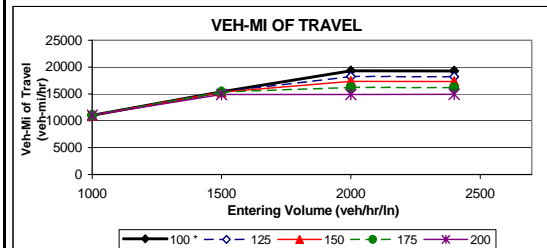
Entering Volume	AVERAGE DENSITY (veh/mi/ln)				
	Car Following Sensitivity Multiplier				
(veh/hr/ln)	100 *	125	150	175	200
1000	17.5	**17.6(1%)**	**17.7(1%)**	**17.9(2%)**	**18.1(4%)**
1500	25.0	**25.4(2%)**	**26.2(5%)**	**28.8(15%)**	**42.6(71%)**
2000	42.2	**52.4(24%)**	**52.2(24%)**	**50.6(20%)**	**50.5(20%)**
2400	53.1	**53.4(1%)**	**51.7(-3%)**	**51.1(-4%)**	**49.9(-6%)**

Entering Volume	AVERAGE DELAY (sec/veh)				
	Car Following Sensitivity Multiplier				
(veh/hr/ln)	100 *	125	150	175	200
1000	8.1	**9.1(12%)**	**10.3(27%)**	**12.1(49%)**	**14.2(74%)**
1500	12.0	**14.8(24%)**	**20.3(70%)**	**36.4(204%)**	**136.5(1039%)**
2000	63.8	**114(78%)**	**132.6(108%)**	**153.4(140%)**	**182.4(186%)**
2400	89.5	**112.7(26%)**	**130.4(46%)**	**156.5(75%)**	**177.6(98%)**
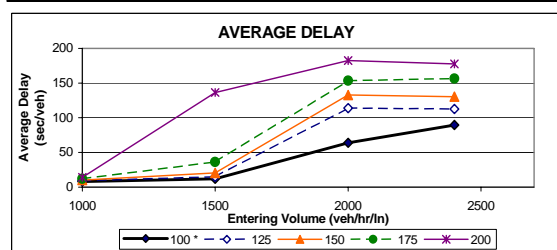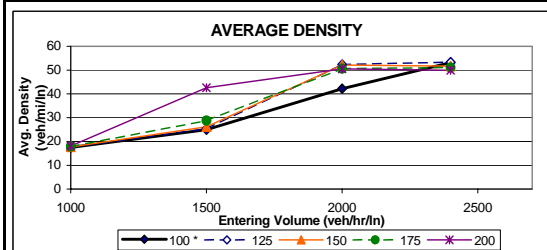
Notes:
* = Default value.
(XX%) = Percent difference from default value.
Bold Value = Value is statistically different from default value (95% confidence level).

Figure 5. Summary of Sensitivity Analysis of Car Following Sensitivity Multiplier on FRESIM System Network.

The summary graphs shown in Figure 5 use the entering volumes as the X-axis, which could be different than the actual volumes in the at-capacity scenarios. Thus, the graphs do not match traditional speed-volume-density graphs typically found in the HCM or other traffic flow theory applications. Demand volume was used in this study because the objective was to understand the sensitivity of the parameters under different uniform scenarios, so it was important to keep the X-axis constant to see how the MOEs varied under each parameter value. Using the actual volume in the X-axis would make it more difficult to directly compare the results of each parameter value, especially when the parameter values experience a slightly different actual volume for the at-capacity scenarios.

5.4 FRESIM Sensitivity Analysis Results

The one-page summaries, like the one shown in Figure 5, for each parameter-network scenario are shown in Appendix A. A number of general trends were observed by evaluating the summary pages, including:

- Most of the parameters showed no sensitivity at the lower congestion levels (entering volumes of 1000 and 1500 veh/hr/lane). In only a few instances did the most extreme sensitivity value produce a statistically significant difference (at a 95% confidence interval) from the default value.

- An entering volume of 2000 veh/hr/lane (approximate V/C ratio of 0.83) experienced more sensitivity within the parameters than that shown with 2400 veh/hr/lane (approximate V/C ratio of 1.0). This trend was likely caused because the at-capacity condition allowed less variability in driver behavior due to more closely spaced vehicles and less maneuverability.

- Average delay was the most sensitive MOE. Average speed and average density, were equally sensitive, and less sensitive than average delay, while throughput and vehicle-miles of travel were the least sensitive.

- Overall, the parameters became more sensitive as the network type became more complex. Thus, the system network generally experienced more sensitivity than the basic 3-lane network, which in turn experienced more sensitivity than the basic 1-lane network.

As stated earlier, the majority of the sensitivity tests were designed as one-sided tests, meaning the parameter values were varied on one side of the default value to represent more cautious driver behavior as would be expected during adverse weather. Based on this one-sided methodology, it was expected that the parameters would experience a general degradation in MOEs (i.e., average speed decreasing and average delay increasing) when changing the parameter values to represent more conservative driver behavior. However, this was not always the case. In fact, the parameters were divided into three "sensitivity groups" based on their general effect on the MOEs as shown in Table 24.

Table 24. CORSIM Parameter Sensitivity Groups.

Sensitivity Group	Description
Expected	Parameter values that consistently produced degradation in MOEs.
Inconsistent	Parameter values that showed no consistent trend between more conservative driver behavior and MOEs.
No Effect	Parameter values that had virtually no effect on the MOEs in any of the network-congestion level scenarios.

Figure 6 shows the sensitivity of average speed on the system network for three parameters representing each sensitivity group. As shown in the figure, the Pitt Car Following Constant follows a consistent and expected trend, the Maximum Emergency Deceleration does not follow a consistent trend, and the Jerk Value shows no sensitivity at all.

PITT CAR FOLLOWING CONSTANT (Default = 10)
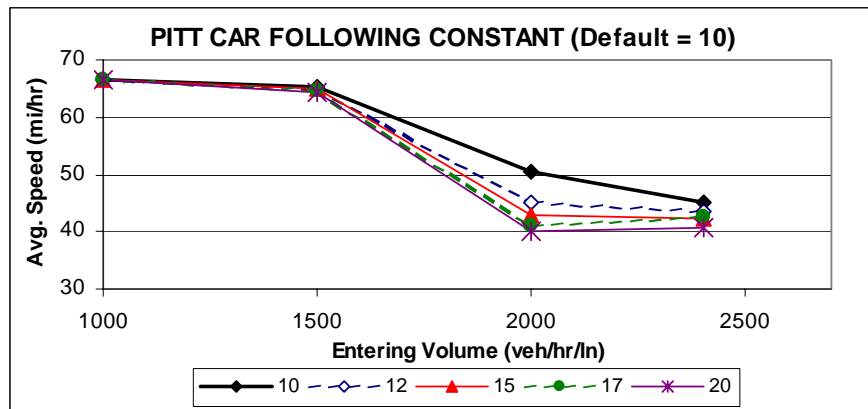
"Expected" Sensitivity Group

MAX. EMERGENCY DECELERATION (Default = 15)
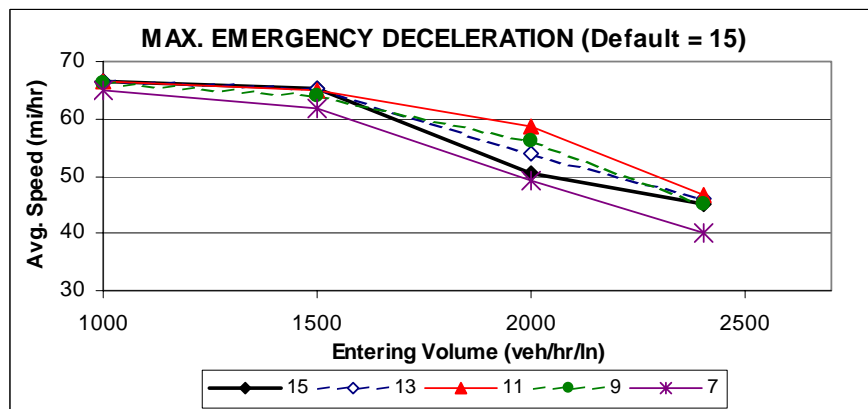
"Inconsistent" Sensitivity Group

JERK VALUE (Default = 7)
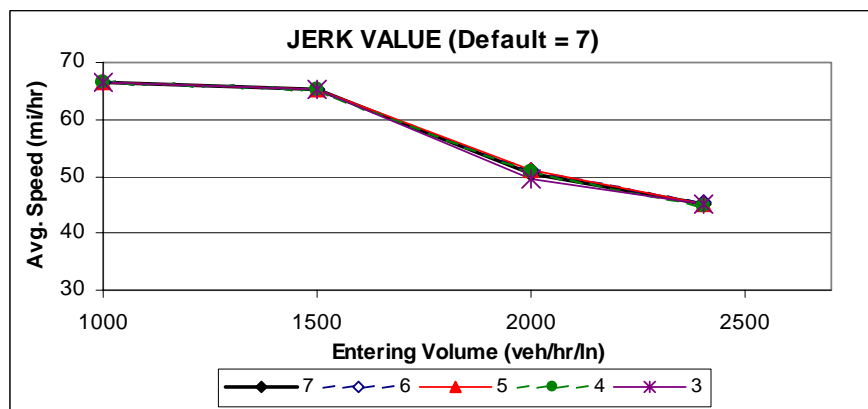
"No Effect" Sensitivity Group

Figure 6. Sample Cases of Average Speed on System Network for Each Sensitivity Group.

Table 25 through Table 27 summarizes the general sensitivity of each freeway parameter tested based on the sensitivity group and general level of sensitivity. Low, medium, or high sensitivity levels are based on an evaluation of the overall sensitivity of the parameter values in each network-congestion level scenario. These are based on relative differences between the parameters and not an absolute sensitivity level.

5.4.1 Sensitivity of Car Following Parameters

Table 25 summarizes the sensitivity of each FRESIM car following parameter.

Table 25. General Sensitivity of FRESIM Car Following Parameters.

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Car Following Sensitivity Factor	0.3*, 0.2, 0.1, 0.0**	No Effect	Low	This parameter overall has little sensitivity when changing the standard deviation of the sensitivity factor by driver types (but keeping the mean constant).
Car Following Sensitivity Multiplier	100*, 125, 150, 175, 200	Expected	High	The most sensitive car following parameter. Value of 125 yields statistically different MOEs than default at medium congestion levels (V/C of 0.63 and higher).
Pitt Car Following Constant	10*, 12, 15, 17, 20	Expected	Medium	CORSIM only allows values from 3 to 10. A modification was made to allow larger values. A value of 12 yields statistically different MOEs than default at higher congestion levels (V/C of 0.83 and higher).
Lag Acceleration /Deceleration Time	1, 3*, 5, 7, 9	Expected	Medium	MOEs worsen as value increases. Value of 5 yields statistically different MOEs on system network than default value. Value of 1 much more sensitive than other values.
Jerk Value	7*, 6, 5, 4, 3	No Effect	Low	Values show no statistically significant sensitivity under any network-congestion level scenario.

Notes: *   - default value.
   ** - These values represent the standard deviation of the car following sensitivity factors for each of the 10 driver types. The default values (range from 1.25-0.35 for Driver Type 1 to 10) equal a mean value of 0.80 and standard deviation of 0.30. Each consecutive alternative has the same mean (0.80) but smaller standard deviation to represent more uniform driver behavior.

The Car Following Sensitivity Multiplier parameter is clearly the most sensitive car following parameter and would be the most practical to manipulate when trying to alter car following behavior. Increasing the Car Following Sensitivity Multiplier value to 125 percent nearly always (more so at 1500 veh/hr/lane entering volume or higher) resulted in a statistically significant degradation in MOEs from the default. An interesting trend was observed with the Car Following Sensitivity Multiplier on the basic 2-lane segment and 3-lane segment networks: increasing the multiplier resulted in increasingly degraded MOEs for the lower entering volume

scenarios, but increasingly improved MOEs for the at-capacity scenarios. One possible inference from this finding is that more conservative car following behavior results in lower quality of service in uncongested conditions, but improved quality of service in congested conditions. However, this finding was not duplicated with the other car following parameters.

The Pitt Car Following Constant and Lag Acceleration/Deceleration Time parameters, while not as sensitive as the Car Following Sensitivity Multiplier, showed consistent and expected results. They also should be considered when attempting to calibrate car following behavior. A Pitt Car Following Constant value of 12 feet yielded statistically degraded MOEs when compared to the default, but generally only at the higher congestion scenarios (entering volume of 2000 veh/hr/lane or higher). (Note: The current version of CORSIM only allows values of the Pitt Constant to vary from 3 to 10. A modification was made to allow larger values for this study.) The Lag Acceleration/Deceleration Time values of 5.0 seconds or higher showed statistical differences at an entering volume of 2000 veh/hr/lane on the system network, but the values were statistically different only at the highest congestion level (2400 veh/hr/lane) on the basic segment networks.

The Jerk Value and Car Following Sensitivity Factor showed no sensitivity under any of the scenarios. However, this does not imply that these parameters have no sensitivity whatsoever. In fact, further testing with different networks and/or at a more detailed analysis level would provide a more complete depiction of the parameter's sensitivity and might reveal a sensitivity that did not show up in these scenarios.

5.4.2   Sensitivity of Lane Changing Parameters

Table 26 summarizes the sensitivity of each FRESIM car following parameter. The lane changing parameters were generally not as stable as the car following parameters, as many produced no clear trends in the MOEs. Some parameters produced a clear trend in one network, but then the opposite trend in another network (e.g., Anticipatory Lane Change Speed). On the other hand, other parameters consistently showed no clear trend in every network (e.g., Maximum Emergency Deceleration). It was interesting that the Maximum Emergency Deceleration and the Leader's Maximum Deceleration as Perceived by Follower parameters had identical impacts on the MOEs in every network and volume level, prompting the question of why are there two different parameters in the model that yield identical results.

The Time to Complete Lane Change parameter produced consistent and expected results at a medium level of sensitivity. Based on this finding, this parameter should be considered first when attempting to calibrate lane changing behavior. The Advantage Threshold for Discretionary Lane Change, Discretionary Lane Change Multiplier, Gap Acceptance Parameter, and Percent Cooperative Drivers parameters showed no sensitivity under any of the scenarios. However, as stated previously, it should not be inferred that these parameters have no sensitivity whatsoever, but rather a more detailed analysis should be completed under different networks and/or a more detailed analysis level to get a more complete depiction of the true parameter sensitivity.

Table 26. General Sensitivity of FRESIM Lane Changing Parameters.

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Time to Complete Lane Change	2.0*, 2.5, 3.0, 3.5, 4.0	Expected	Medium	Value of 3.0 yields statistically different MOEs for most networks at higher congestion levels.
Advantage Threshold for Discretionary Lane Change	0.4*, 0.5, 0.6, 0.7, 0.8	No Effect	Low	This parameter overall has little sensitivity, with the exception of average delay at the highest congestion level.
Discretionary Lane Change Multiplier	5*, 4, 3, 2, 1	No Effect	Low	This parameter overall has little sensitivity.
Gap Acceptance Parameter	3*, 4, 5, 6	No Effect	Low	This parameter overall has little sensitivity.
Percent Cooperative Drivers	20*, 30, 40, 50, 100	No Effect	Low	This parameter has very little sensitivity, even at the maximum value (100%).
Maximum Non-Emergency Deceleration	8.0*, 7.0, 6.0, 5.0, 4.0	Inconsistent	Medium	MOEs improve as value decreases. Value of 6.0 yields statistically different MOEs on most scenarios.
Maximum Emergency Deceleration	15*, 13, 11, 9, 7	Inconsistent	Medium	MOEs improve as value decreases, except for a value of 7, which often yields worse MOEs.
Leader's Maximum Deceleration as Perceived by Follower	15*, 13, 11, 9, 7	Inconsistent	Medium	Identical results as "Maximum Emergency Deceleration" parameter.
Anticipatory Lane Change Distance	2500, 2000, 1500*, 1000, 500	Inconsistent	Medium	No clear trend between distance and MOEs (different trend in each network).
Anticipatory Lane Change Speed	43*, 35, 30, 25, 20	Inconsistent	Medium	No clear trend between this parameter and MOEs. System and merge networks show improvement in MOEs as speed decreases, but weave network shows degradation in MOEs.

Notes: * - default value.

5.4.3   Sensitivity of Free Flow Speed Parameters

Table 27 summarizes the sensitivity of each FRESIM free flow speed parameter.

Table 27. General Sensitivity of FRESIM Free Flow Speed Parameters.

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Mean Free Flow Speed	70*, 60, 50, 40, 30	Expected	High	The most sensitive of all parameters tested. A value of 60 yielded statistically different MOEs than the default value for all networks.
Free Flow Speed Multiplier **	0.78*, 0.54, 0.27, 0.00**	Inconsistent	Medium	No clear trend between standard deviation and MOEs (different trend in each network.) Basic networks have high sensitivity at higher congestion levels but other networks show little sensitivity.

Notes: * - default value.

  ** - These values represent the standard deviation of the free flow speed multiplier for each of the 10 driver types. The default values (range from 0.88 to 1.22 for Driver Type 1 to 10) equal a mean value of 1.0 and standard deviation of 0.78. Each consecutive alternative has the same mean (1.0) but smaller standard deviation to represent more uniform driver behavior.

The Mean Free Flow Speed parameter was the most sensitive of all parameters studied. A free flow speed of 60 mi/hr yielded statistically different results under all scenarios compared to the default value (70 mi/hr). This sensitivity study confirms past research showing that the free flow speed parameter is a crucial parameter to alter when modeling weather events on freeway networks. However, the Free Flow Speed Multiplier parameter, which was tested by changing the distribution of speed by driver type while maintaining the same mean speed, showed no clear trend in its impact on the MOEs. Further, changing the multipliers so that each driver type has the same free flow speed (or zero standard deviation) yielded average speeds equal to the free flow speed on the basic segment networks, which is an unrealistic result at the higher volume levels because all other test scenarios showed a gradual decrease in average speed with an increase in entering volume.

5.5   NETSIM Sensitivity Analysis Results

The one-page summaries, like the one shown in Figure 5, for each NETSIM parameter-network scenario are displayed in Appendix B. The evaluation of the summary pages resulted in the following trends:

- The number of lane changes was the most sensitive MOE relative to the other MOEs. Average delay and average speed both showed moderate sensitivity, while throughput and vehicle-miles of travel displayed the least sensitivity relative to the other MOEs.

- For the basic segment networks, the parameters became increasingly sensitive as the V/C ratio increased. However, like the freeway parameters, the arterial parameters were generally slightly more sensitive at the just-below capacity (V/C ratio around 0.8) than the at-capacity conditions. This trend is thought to occur because the at-

capacity condition allowed less variability in driver behavior due to more closely spaced vehicles and less maneuverability.

- For the intersection networks, the MOEs degraded dramatically when the V/C ratio approached 1.0.

Table 28 through Table 33 summarizes the general sensitivity of each network parameter tested based on the sensitivity group (refer to Table 24) and general level of sensitivity.

5.5.1 Sensitivity of Car Following Parameters

Table 28 displays the general sensitivity of the NETSIM car following parameter.

Table 28. General Sensitivity of NETSIM Car Following Parameters.

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Time to React to Sudden Deceleration Of Lead Vehicle	0.5, 1.0*, 1.5, 2.0, 2.5	Expected	High	Values of 1.5 and higher yield statistically degraded MOEs with basic and system networks under all congestion levels. Intersection networks show slightly less sensitivity.

Notes: * - default value.

As described previously, there is not a detailed car following model in NETSIM, primarily because the movement of vehicles on surface streets are controlled more by lane changing behavior and reacting to traffic control devices than basic car following behavior. For the Time to React to Sudden Deceleration of Lead Vehicle parameter, significant degradation in the MOEs were observed as the parameter value increased for the basic segment and system networks. However, for the single intersection networks, especially the urban intersection, the parameter changes had little effect on the MOEs. The small effect on the intersection networks is logical given that vehicle movement was likely controlled mainly by reaction to the traffic signal and queues upstream of the signal.

It should be noted that the Time to React to Sudden Deceleration of Lead Vehicle parameter also affects lane changing behavior, as seen in the next section.

5.5.2 Sensitivity of Lane Changing Parameters

Table 29 displays the general sensitivity of the NETSIM lane changing parameters.

Table 29. General Sensitivity of NETSIM Lane Changing Parameters.

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Driver Type Factor	15, 25*, 35, 45, 50	No Effect	Low	No sensitivity, not even at a value of 50, to any network-congestion level combination.
Urgency Threshold	2*, 2.5, 3, 4, 5	No Effect	Low	Very low sensitivity. In a few cases a value of 5 yielded differences of 2-3% from default value, but never at statistically significant level.
Minimum Deceleration for a Lane Change	5*, 4, 3, 2, 1	Expected	Medium	Statistically significant decreases in number of lane changes (up to 20%), but none for other MOEs.
Difference in Minimum/Maximum Deceleration for Mandatory Lane Changes	10*, 9, 7, 6, 5	No Effect	Low	Very low sensitivity. MOEs did not change at statistically significant level in any network-congestion level combination.
Difference in Minimum /Maximum Deceleration for Discretionary Lane Changes	5*, 4, 3, 2, 1	No Effect	Low	Statistical increase in the number of lane changes in some cases under non-congestion level (up to 10%). Very low sensitivity on other MOEs.
Safety Factor	8.0*, 7.5, 7.0, 6.5, 6.0	No Effect	Low	Moderate reduction in number of lane changes when safety factor is 6 and volumes are high (4-6 % reduction). A few cases yielded differences of 1-3%, but no statistical significance.
Headway at Which All Vehicles Attempt Lane Change	2.0*, 1.8, 1.5, 1.2, 1.0	No Effect	Low	Very low sensitivity. The number of lane changes decreased in all networks (0-4%). Very low sensitivity on other MOEs.
Headway at Which No Vehicles Attempt Lane Change	5.0*, 4.5, 4.0, 3.5, 3.0	No Effect	Low	Very low sensitivity. The number of lane changes decreased in all networks (Maximum 2%). Very low sensitivity on other MOEs.
Time to React to Sudden Deceleration Of Lead Vehicle	0.5, 1.0*, 1.5, 2.0, 2.5	Expected	High	Values of 1.5 and higher yield statistically degraded MOEs with basic and system networks under all congestion levels. Intersection networks show slightly less sensitivity.
Duration of a Lane Change	3*, 5, 6, 7, 8	No Effect	Low	Low sensitivity. The number of lane changes decreased slightly (5% max. at the significant level). Very low sensitivity on other MOEs.
Percent Drivers Who Cooperate With Lane Changer	10, 25, 50*, 75, 100	No Effect	Low	At value of 10, the number of lane changes drops by up to 12%. A maximum 10% increase in average speed on the suburban intersection with a value of 100 (not statistically significant difference)
Distance Over Which Drivers Perform Lane Change	300*, 500, 700, 900, 1100	No Effect	Low	Very low sensitivity.

Table 29 (continued).

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Distribution of Distance to Attempt a Lane Change	17.1*, 11.4, 6.1, 0.0**	No Effect	Low	No sensitivity was shown at all, not even a 1% difference at a standard deviation of 0.0.
Deceleration of Lead Vehicle	12*, 11, 10	Expected	Medium	The number of lane changes decreased dramatically, as much as 100%. The basic networks experienced statistical decreases in average speed (2-4%) and delay (up to 20%).
Deceleration of Following Vehicle	12*, 11, 10	Expected	Medium	The number of lane changes decreased dramatically, as much as 90%. The basic networks experienced statistical decreases in average speed (1-6%) and delay (up to 44%).

Notes: * - default value.

** - These values represent the standard deviation of the distance to attempt a lane change for each of the 10 driver types. The default values (range from 125 to 75 percent for Driver Type 1 to 10) equal a mean value of 100 and standard deviation of 17.1. Each consecutive alternative has the same mean (100) but smaller standard deviation to represent more uniform driver behavior.

As shown in the table, there are a total of 15 lane changing parameters in NETSIM. Of these parameters, 11 had very little sensitivity overall on the MOEs. Typically these parameters had some small, quantifiable change on the number of lane changes, but very little and not statistically significant impact on the other MOEs. It should be emphasized that this study does not prove that these parameters have no sensitivity whatsoever. Testing of different networks or use of different MOEs could reveal additional sensitivity not discovered in this study. For example, examination of more disaggregate MOEs, such as vehicle trajectory data, could reveal sensitivity of the parameters at a level which is not possible with aggregate MOEs such as average speed over an entire link.

The Time to React to Sudden Deceleration of Lead Vehicle parameter impacted the number of lane changes dramatically (up to 90 percent increase on the basic segment networks and 30 percent on the other networks.) The other MOEs changed at a more modest but still significant level.

The Minimum Deceleration for a Lane Change had a moderate impact on the number of lane changes (up to 20 percent change), but no statistically significant changes in the other MOEs.

The Deceleration of Lead Vehicle and Deceleration of Following Vehicle parameters showed a medium level of sensitivity (relative to the other parameters), with a significant decrease in the number of lane changes and more moderate, but still statistically significant, change in average speed and average delay. It is interesting that CORSIM will not allow users to enter a value for these parameters less than 10 (allowable range of 10 to 15). Future consideration should be given to widening this allowable range given that it is one of the few lane changing parameters that has a quantifiable impact on MOEs.

5.5.3 Sensitivity of Free Flow Speed Parameters

Table 30 displays the general sensitivity of the NETSIM free flow speed parameters.

Table 30. General Sensitivity of NETSIM Free Flow Speed Parameters.

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Mean Free Flow Speed	45*, 40, 35, 30, 25	Expected	High	Average speed and delay changed significantly at all congestion levels (average speed reduced 12% at 40 mph and 46% at 25 mph), but throughput was not as sensitive (no statistical differences).
Free Flow Speed Multiplier	16*, 11.4, 5.4, 0.0**	Inconsistent	Medium	Reducing the standard deviation improves the MOEs on the basic segment networks (up to 25% increase in average speed), but no statistical differences on other networks.

Notes: * - default value.

** - These values represent the standard deviation of the free flow speed multiplier for each of the 10 driver types. The default values (range from 75 to 127 percent for Driver Type 1 to 10) equal a mean value of 100 and standard deviation of 16.0. Each consecutive alternative has the same mean (100) but smaller standard deviation to represent more uniform driver behavior.

The Mean Free Flow Speed parameter was the most sensitive of all NETSIM parameters studied. For example, lowering the Mean Free Flow Speed from 45 to 25 mi/hr resulted in a 450 percent increase in total delay and 45 percent decrease in average speed on the basic 2-lane segment. This finding that the MOEs are very sensitive to changes in free flow speed is similar to that found in the FRESIM sensitivity analysis.

The Free Flow Speed Multiplier represents a distribution of free flow speeds based on driver type. It was found that more uniform free flow speeds (lower standard deviation) resulted in fewer lane changes. In addition, the other MOEs (except for throughput) improved on the basic segment networks (up to 25 percent increase in average speed), but no statistically significant changes were found on the other networks. The Free Flow Speed Multiplier did not affect the throughput on the basic 1-, 2-, and 3-lane segment networks. The improvement on the basic segment networks were similar to that found in the FRESIM sensitivity analysis.

5.5.4 Sensitivity of Discharge Headway Parameters

Table 31 displays the general sensitivity of the NETSIM discharge headway parameters.

The Mean Discharge Headway is a very sensitive NETSIM parameter as shown in the table. Generally, as the discharge headway increased, the MOEs became more degraded. Stopped delay was the most affected MOE (up to 1800 percent increases), while the number of lane changes was the least affected MOE (maximum change of 20 percent.)

Changing the distribution of the Discharge Headway Multiplier (while maintaining the same mean value) did not statistically impact any of the networks during any congestion level.

Table 31. General Sensitivity of NETSIM Discharge Headway Parameters.

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Mean Discharge Headway	1.9*, 2.2, 2.5, 2.7, 3.0	Expected	High	Stop delay increased 1300% and throughput decreased 35% at 3.0 on the suburban intersection.
Discharge Headway Multiplier	33.7*, 20.2, 10.1, 0.0**	No Effect	Low	No statistical differences were observed in any network-congestion level combination.

Notes: * - default value.
    ** - These values represent the standard deviation of the discharge headway multiplier for each of the 10 driver types. The default values (range from 170 to 50 percent for Driver Type 1 to 10) equal a mean value of 100 and standard deviation of 33.7. Each consecutive alternative has the same mean (100) but smaller standard deviation to represent more uniform driver behavior.

5.5.5   Sensitivity of Start-Up Delay Parameters

Table 32 displays the general sensitivity of the NETSIM start-up delay parameters.

Table 32. General Sensitivity of NETSIM Start-Up Delay Parameters.

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Mean Start-Up Delay	1.3*, 1.5, 1.7, 1.9, 2.1	Expected	High	Stop delay increased 47% and throughput decreased only slightly (2%) at a value of 2.1 on the suburban intersection.
Start-Up Delay Multiplier	55*, 37, 16.8, 0.0**	No Effect	Low	No statistical differences were observed in any network-congestion level combination.

Notes: * - default value.
    ** - These values represent the standard deviation of the start-up delay multiplier for each of the 10 driver types. The default values (range from 218 to 23 percent for Driver Type 1 to 10) equal a mean value of 100 and standard deviation of 55. Each consecutive alternative has the same mean (100) but smaller standard deviation to represent more uniform driver behavior.

The start-up delay parameters had a similar effect on the MOEs as the discharge headway parameters, but with slightly less severity as this parameter only affects the first few vehicles in a queue. For example, throughput and the number of lane changes were minimally impacted (maximum of two and six percent, respectively). Generally, as the start-up delay increased, the MOEs subsequently degraded. Stop delay was the most affected MOE (increases of up to 47 percent), while average speed dropped only up to 10 percent. The changes in average delays were impacted as well (up to 37 percent). The changes in average delays were greatest in the urban network, while the system network was the least impacted network overall.

Changing the distribution of the Start-Up Delay Multiplier (while maintaining the same mean value) did not statistically impact any of the networks during any congestion level.

5.5.6 Sensitivity of Turning Speed Parameters

Table 33 displays the general sensitivity of the NETSIM turning speed parameters.

Table 33. General Sensitivity of NETSIM Turning Speed Parameters.

Parameter	Parameter Values	Sensitivity Group	Sensitivity Level	Comments
Max. Allowable Left Turn Speed	22*, 18, 14, 10, 6	Expected	Medium	The largest difference was a 12% increase (which was statistically significant) in stopped delay at 6 mph on the urban intersection.
Max. Allowable Right Turn Speed	13*, 11, 9, 7, 5	Expected	Medium	The largest difference was a 15% increase (which was statistically significant) in stopped delay at 5 mph on the urban intersection.

Notes: * - default value.

Decreasing the turning speeds produced an expected degradation in the MOEs. The MOEs were most affected at the higher congestion levels, as vehicles were more closely spaced and thus delayed more by vehicles turning at a slower rate. Stopped delay was the most affected MOE, as stopped delays increased approximately 10 to 15 percent on the urban intersection during the highest congestion levels. The left and right turning speeds were approximately equally sensitive on the test networks.

5.6   Summary of Sensitivity Analysis

The purpose of the sensitivity study was to identify the most sensitive weather-related parameters in CORSIM. The study focused on car following, lane changing, and free flow speed parameters on freeways (FRESIM) and car following, lane changing, free flow speed, discharge headway, start-up lost time, and turning speed parameters on arterial streets (NETSIM). Each test parameter was modeled on various geometric networks and congestion (volume) levels using the default value and then changing the value to represent incrementally more conservative driver behavior, as would occur under adverse weather. The MOEs produced by the default value were then compared to the MOEs produced with the changed parameter values to determine the level of sensitivity the parameter has on the MOEs.

One interesting result of the study was a number of parameters had little or no impact on the MOEs. Table 34 summarizes the tested parameters that had no effect on the MOEs.

As Table 34 shows, the majority of the parameters with no sensitivity were lane changing parameters. In fact, 11 of the 15 lane changing parameters in NETSIM showed no sensitivity. These non-sensitive parameters should be the focus of further research because it is not clear why many of them did not have a greater impact on the MOEs. However, this study does not prove that these parameters have no sensitivity whatsoever. Testing of different networks or use of different MOEs could reveal additional sensitivity not discovered in this study. For example, examination of more disaggregate MOEs, such as vehicle trajectory data, could reveal sensitivity of the parameters at a level which is not possible with aggregate MOEs such as average speed over an entire link. The fact that most of these lane changing parameters had at least some small impact on the number of lane changes shows that the parameters were affecting traffic operations to some degree.

Table 34. Traffic Parameters With No Effect on MOEs.

Parameter Category	Parameter
FRESIM	
Car Following	- Car Following Sensitivity Factor - Jerk Value
Lane Changing	- Advantage Threshold for Discretionary Lane Change - Discretionary Lane Change Multiplier - Gap Acceptance Parameter - Percent Cooperative Drivers
NETSIM	
Car Following	None
Lane Changing	- Driver Type Factor - Urgency Threshold - Headway at Which All Vehicles Attempt a Lane Change - Headway at Which No Vehicle Attempt a Lane Change - Difference in Min/Max Deceleration for Mandatory Lane Changes - Difference in Min/Max Deceleration for Discretionary Lane Changes - Safety Factor - Duration of a Lane Change - Percent Drivers Who Cooperate With a Lane Changer - Distance Over Which Drivers Perform a Lane Change - Distribution of Distance to Attempt a Lane Change
Discharge Headway	- Discharge Headway Multiplier
Start-Up Lost Time	- Start-Up Lost Time Multiplier
Turning Speed	None

In addition to the non-sensitive parameters, a number of FRESIM lane changing parameters had an "inconsistent" impact on the MOEs, named so because they had no consistent impact on the MOEs. These inconsistent parameters included the Maximum Non-Emergency Deceleration, Maximum Emergency Deceleration, Leader's Maximum Deceleration as Perceived by Follower, Anticipatory Lane Change Distance, and Anticipatory Lane Change Speed. These parameters should also be the focus of more-detailed research to further determine how they function within the various model algorithms and exactly what impact they have on traffic operations.

Table 35 summarizes those parameters that had both an expected effect on the MOEs and were categorized as either having a medium or high effect on the MOEs (relative to the other parameters.) This table is important because it identifies the key weather-related driver behavior parameters that should be altered when trying to model weather events in CORSIM. As stated earlier, this study does not recommend specific values to use for these parameters during various weather events, but it does identify these parameters as the most sensitive and therefore should be the focus when calibrating a model for a specific weather event. A traffic analyst should first focus on the parameters with a high sensitivity level, and then if further calibration is needed could use those with a medium sensitivity level.

Table 35. Traffic Parameters With Expected and Medium-to-High Effect on MOEs.

Parameter Category	Parameter
FRESIM	
Car Following	- *Car Following Sensitivity Multiplier (High)*
	- Pitt Car Following Constant (Medium)
	- Lag Acceleration/Deceleration Time (Medium)
Lane Changing	- Time to Complete Lane Change (Medium)
Free Flow Speed	- *Mean Free Flow Speed (High)*
NETSIM	
Car Following	- *Time to React to Sudden Deceleration Of Lead Vehicle (High)*
Lane Changing	- *Time to React to Sudden Deceleration Of Lead Vehicle (High)*
	- Minimum Deceleration for a Lane Change (Medium)
	- Deceleration of Lead Vehicle (Medium)
	- Deceleration of Following Vehicle (Medium)
Free Flow Speed	- *Mean Free Flow Speed (High)*
Discharge Headway	- *Mean Discharge Headway (High)*
Start-Up Lost Time	- *Mean Start-Up Delay (High)*
Turning Speed	- Max. Allowable Left Turn Speed (Medium)
	- Max. Allowable Right Turn Speed (Medium)

Due to the large number of networks and variables tested in the sensitivity study, a number of additional findings and recommendations were made that were somewhat unrelated to the task of determining the most sensitive parameters, but nonetheless were thought to be important for CORSIM users in general. These findings can be summarized as follows:

- The Minimum Separation for Generation of Vehicles parameter is a useful parameter in calibrating the capacity of basic freeway segments, but users should realize that changing the driver behavior parameters (specifically the Car Following Sensitivity Multiplier) can also limit the freeway capacity in some cases.

- The Minimum Separation for Generation of Vehicles parameter is only available on freeways (FRESIM) and not on surface streets (NETSIM). As a result, arterial volumes up to 2700 veh/hr/lane can be modeled in NETSIM, which is not realistic for arterials. However, the capacity will likely be limited by traffic signals on arterials, but nevertheless traffic analysts should be careful to model realistic traffic volumes on arterial streets.

- In FRESIM, the Maximum Emergency Deceleration and Leader's Maximum Deceleration as Perceived by Follower parameters are identical parameters, as they produced exactly equal results in the sensitivity analysis.

- Changing the distribution of speeds for the Free Flow Speed Multiplier is not recommended because they produced inconsistent (and unrealistic for a distribution with very low standard deviation) impacts on the MOEs. In addition, changing the distribution of Discharge Headways and Start-Up Delays in NETSIM is also not recommended because altering them had no effect on the MOEs.

- Future consideration should be given to widening the allowable range for the Deceleration of Lead Vehicle and Deceleration of Following Vehicle parameters given that they are two of the only NETSIM lane changing parameters that have a quantifiable impact on MOEs.

Currently, the allowable range is 10 to 15 ft/sec/sec with a default value of 12 ft/sec/sec. The allowable range for the Pitt Car Following Constant should also be widened (currently 3 to 10 feet with a default value of 10 feet) to at least 15 feet to allow users to model more conservative car following behavior.

- The Highway Capacity Manual recommends a default mean start-up delay of 2.0 seconds, which is defined as the extra time consumed by the first few vehicles in a signalized intersection queue. In the absence of localized field data, it is recommended that CORSIM users use this value of 2.0 seconds, which means the default Mean Start-Up Delay value should be changed to 1.3 seconds (currently 2.5 seconds) because 0.7 seconds of start-up delay is already "hard-coded" into the model for the second and third vehicles in the queue.

6   Guidelines for Modeling Weather Events in CORSIM

The purpose of this section is to provide practical guidelines for modeling the effects of adverse weather on a roadway network using CORSIM. The guidelines presented here are based on *Guidelines for Applying Traffic Microsimulation Modeling Software* (*18*), a FHWA guidance document on the development and application of microsimulation models. Figure 7 shows the seven-step process recommended in the guidelines for developing a microsimulation model and how to apply the model to analyze various alternatives.

Even though the process shown in Figure 7 was not designed specifically for modeling weather events, a traffic analyst intent on modeling weather effects should not forget the importance of scoping the project, collecting field data, developing the base model, checking the model for errors, calibrating the model to local conditions, analyzing alternatives, and producing a final report.

Figure 7 lays the foundation for the development and application of an accurate and valid CORSIM model. The same basic steps shown in Figure 7 should be followed even when including the impacts of adverse weather. However, there are a few steps in the process that a traffic analyst should approach slightly differently when modeling adverse weather in CORSIM. These differences are highlighted in the remainder of this section.
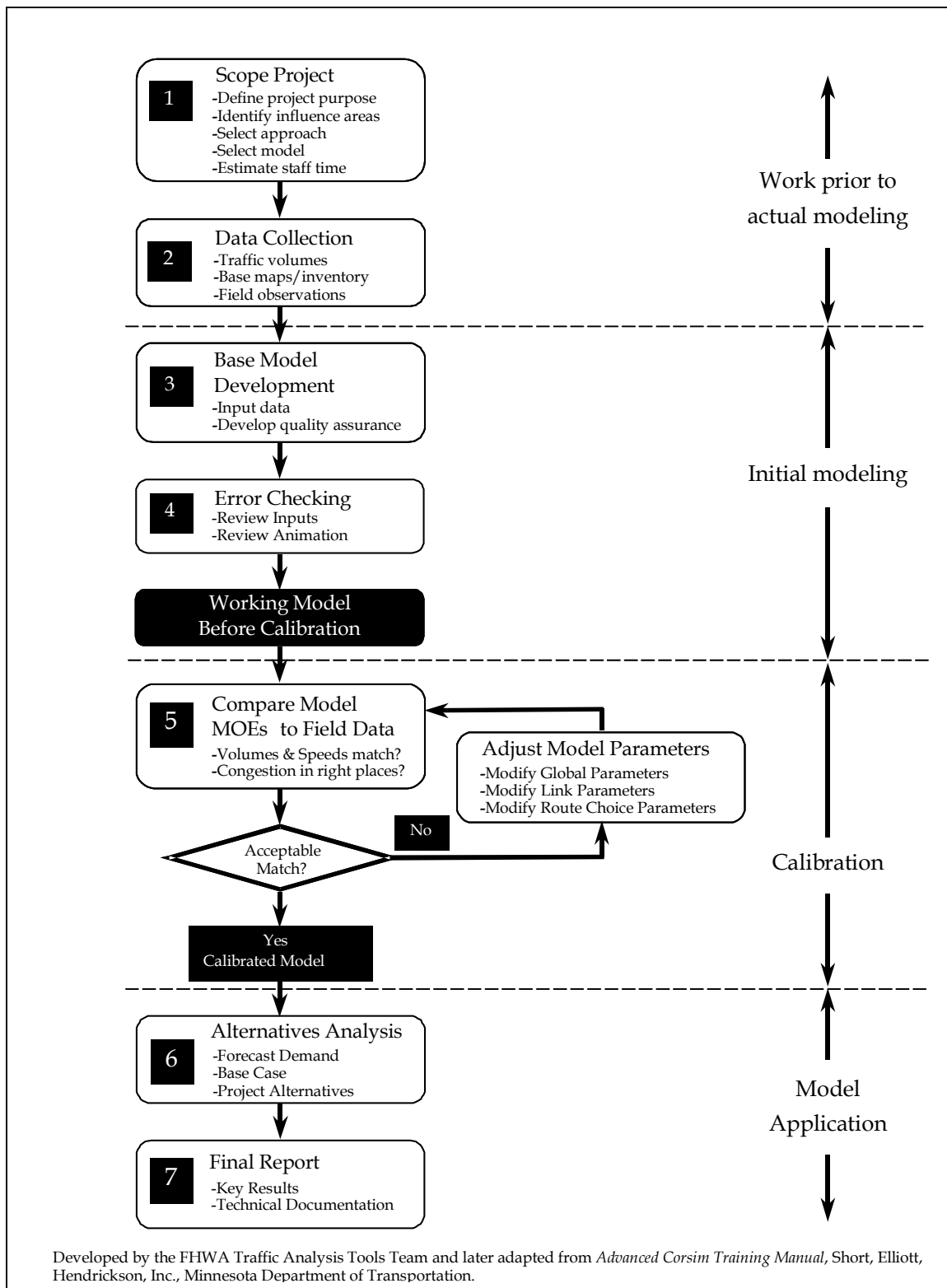
1	**Scope Project** -Define project purpose -Identify influence areas -Select approach -Select model -Estimate staff time
2	**Data Collection** -Traffic volumes -Base maps/inventory -Field observations
3	**Base Model Development** -Input data -Develop quality assurance
4	**Error Checking** -Review Inputs -Review Animation

Working Model Before Calibration

5	**Compare Model MOEs to Field Data** -Volumes & Speeds match? -Congestion in right places?

Adjust Model Parameters
-Modify Global Parameters
-Modify Link Parameters
-Modify Route Choice Parameters

Acceptable Match?

No

Yes
Calibrated Model

6	**Alternatives Analysis** -Forecast Demand -Base Case -Project Alternatives
7	**Final Report** -Key Results -Technical Documentation

Work prior to actual modeling

Initial modeling

Calibration

Model Application

Developed by the FHWA Traffic Analysis Tools Team and later adapted from *Advanced Corsim Training Manual*, Short, Elliott, Hendrickson, Inc., Minnesota Department of Transportation.

Figure 7. Microsimulation Model Development and Application Process (*18*).

6.1   Step 1 – Scope Project

It is important to define the project scope in any application of a microsimulation model. However, when using the model to include the effects of adverse weather, a few additional considerations are necessary, including:

- Does the selected microsimulation software package have an adequate number of weather-related parameters (see Tables 2 through 6) that can be appropriately adjusted to accurately model the weather impacts?
- What type of weather event(s) will be modeled (e.g., snow, rain, fog, sun glare, or some combination)?
- What is the severity of the weather event(s) being modeled (e.g., two inches or two feet of snow)?
- What is the duration of the weather event(s) being modeled (e.g., will it last the entire simulation period, or just for a short period)?
- What is the extent of the weather event(s) being modeled (e.g., will it cover the entire simulation model area, or just a portion)?

These are important questions that should be answered and agreed on by all parties involved with developing and reviewing the model before beginning the actual model coding. The first question listed may be the most important of the entire project because it determines whether the selected software package is able to successfully include the effects of adverse weather. For CORSIM, the previous sections of this report have shown that CORSIM can successfully be applied to model weather events and does generally have adequate parameters to account for most weather events.

6.2   Step 2 – Data Collection

Collection of actual roadway conditions in the field is important in any application of a microsimulation model. Typical data collected includes traffic volumes, roadway geometrics, signal timing data, transit and pedestrian data, and calibration data (or MOEs) such as capacities, travel times, intersection delays, and queue lengths. When modeling the effects of adverse weather, it is important to attempt to collect data during the weather events being modeled. For example, if the capacity and delay at an intersection is collected during heavy rain, those values obtained can be used to better calibrate a model taking into account heavy rain.

In addition to calibration data (MOEs), traffic parameter data (inputs to the traffic model) are also helpful to collect in the field during the weather events being modeled. Key weather-impacted traffic parameters identified in this sensitivity study and the literature review include: free flow speed, car following sensitivity multiplier, discharge (saturation) headway, start-up delay, and traffic demand.

Collecting these data in the field and using them as inputs to the microsimulation model will provide a more accurate starting point when going through the calibration process (Step 5 in Figure 7).

It is recognized that resources and budgets often make it difficult to perform an exhaustive data collection effort for ideal weather conditions let alone for adverse weather. However, it should also be recognized that the quality of data collection is proportional to the overall quality of the microsimulation model. Therefore, if including the impacts of adverse weather is an important component in the project, then serious consideration should be given to some form of data collection during the weather event(s) being modeled.

In light of this, if field data collection during the weather event(s) being modeled is not possible or practical, then traffic analysts could use the findings of past research (see Section 3) as a starting point when altering traffic parameters to more accurately reflect weather events.

6.3   Step 3 – Base Model Development

This step includes the initial setup and coding of the microsimulation model and inputting the data collected in the field into the model. When including a weather event in the model, the following additional steps are necessary during the base model development:

1.   Identify which traffic parameters are impacted by the weather event.

2.   Determine the appropriate values for these weather-impacted parameters either by (in order of preference):

  - field data collection,
  - findings of past research, or
  - engineering judgment.

For the first step, Table 36 can be used to determine which CORSIM parameters are affected by weather events. This table was developed by matching the generic traffic parameters identified in Tables 2 through 6 (Section 4) to specific CORSIM parameters. To use the table, a traffic analyst must first determine how the weather event being modeled impacts the roadway environment. Figure 3 of this report (Section 2) displays which weather events impact the roadway environment.

As an example, suppose a traffic analyst wants to use CORSIM to model the effects of a heavy snowstorm (say four inches in an hour) on a local roadway network. From Figure 3, it can be seen that a snow event (especially a heavy snowstorm) will likely cause a reduction in driver visibility and pavement friction, and the storm could block lanes or cover signs and pavement markings. The traffic analyst would make the final determination whether the modeled snowstorm should include blocked lanes and covered signs and pavement markings. Based on these roadway environment impacts, the traffic analyst would then use Table 36 to determine specific parameters in CORSIM that may need to be altered due to the snowstorm.

Table 36. CORSIM Parameters Impacted by Weather Events.

Generic Traffic Parameter	Roadway Environment Impact	CORSIM Parameter(s)	Details
ROAD GEOMETRY PARAMETERS			
Pavement condition	Reduced pavement friction	Pavement Condition	Available in FRESIM (freeways) only. Parameter creates an upper bound for the mean free flow speed.[1]
Number of lanes	Blocked lanes	Number of lanes	Can reduce the number of lanes based on the weather event.
Lane width	Blocked lanes	Lane width	Available in NETSIM only. Only changes the graphical display and not traffic operations.
Lane taper length	Blocked lanes	None	No parameter for length or type of taper, but can reduce the length of Deceleration/ Acceleration lanes (in FRESIM) themselves as surrogate.
Shoulder width	Blocked lanes	None	No parameter for shoulder width in FRESIM or NETSIM.
TRAFFIC CONTROL AND MANAGEMENT PARAMETERS			
Traffic signal/ Ramp meter	Reduced visibility	Forward Sight Distance	No parameter to reduce the visibility of a signal/meter itself. Forward Sight Distance parameter specifies sight distance from a stop line at a NETSIM intersection.
	Failed traffic control devices	Traffic signal/ Ramp meter properties	Can change the control to all-way or two-way stop to simulate flash or black-out conditions. For ramp meter, can turn off the meter for specific time periods.
Roadway signs (regulatory, warning, traveler info.)	Reduced visibility	Anticipatory Lane Change Distance, Off-Ramp Reaction Point	No parameter specifically for reducing the visibility of a sign itself. Can change the Anticipatory Lane Change Distance and Off-Ramp Reaction Point as surrogates to seeing exit signs on freeways.
Surveillance detectors	Failed communications	Detector properties	Can delete detectors to simulate failed detector communications.
On-street parking	Blocked lanes	Curb Parking	Can disallow on-street parking for specific time periods.
VEHICLE PERFORMANCE PARAMETERS			
Accel./Decel. Capability	Reduced friction/stability	Acceleration Tables	Can change acceleration tables, including max. acceleration, using RT 173.
Turning radius	Reduced friction/stability	Minimum Drawn Radius of Curvature	Only changes the graphical display and not traffic operations.
TRAFFIC DEMAND PARAMETERS			
Vehicle demand	All[2]	Entry volume and turning volume	Entry volumes for each entering link can be adjusted as appropriate, and turning volumes can be adjusted depending on the weather event.
Route choice	All[2]	Traffic assignment properties	Available in NETSIM only. Cannot change impedances for individual links to simulate weather events.

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Table 36 (continued).

Generic Traffic Parameter	Roadway Environment Impact	CORSIM Parameter(s)	Details
DRIVER BEHAVIOR PARAMETERS			
Car following	All[2]	See Tables 11 and 18	See Table 35 for key parameters.
Lane changing	All[2]	See Tables 12 and 19	See Table 35 for key parameters.
Free flow speed	All[2]	Mean Free Flow Speed and Multipliers	Mean Free Flow Speed on all affected links should be changed according to the weather event.
Discharge headway	All[2]	Mean Discharge Headway and Multipliers	Mean Discharge Headway (at signalized intersections) should be changed according to the weather event.
Start-up delay	All[2]	Mean Start-Up Delay and Multipliers	Mean Start-Up Delay (at signalized intersections) should be changed according to the weather event.
Intersection gap acceptance	All[2]	Acceptable Gap in Oncoming Traffic (AGOT), Cross-Street Traffic Acceptable Gap (CSTAG)	Change AGOT for turns at a traffic signal (permitted left turns and right turns on red) and CSTAG for movements at stop signs.
Turning speed	All[2]	Max. Allowable Left/Right Turn Speed	Can change max. left and/or right turn speeds in NETSIM.
Response to yellow interval	All[2]	Amber Interval Response	Defines the acceptable deceleration for a vehicle to stop at a traffic signal.

Notes: 1. Check CORSIM manual for more details (*11*).
2. All roadway environment changes could impact the parameter.

Once the weather-impacted CORSIM parameters are selected from Table 36, then the proper value for them needs to be determined. As mentioned previously, determining the appropriate values should be done ideally through field data collection. Given that this is often not possible and/or practical for some parameters, the correct parameter values could then be estimated through the findings of past research. See Section 3 of this report for a review of relevant past research. It is important to only use past research that was collected on roadway facilities, congestion levels, and other field characteristics similar to those being modeled. Finally, in the absence of field data collection and past research, engineering judgment can be used to estimate the correct parameter values. For example, it is difficult to collect lane changing parameter data in the field, and there are no past studies regarding lane changing behavior in adverse weather. Thus, in this case, changing the lane changing parameters to represent slightly more conservative driver behavior (as would likely happen in adverse weather) would probably be a reasonable choice based on engineering judgment.

While Table 36 shows the range of traffic parameters impacted by weather events, it may not be possible or practical to change all of the impacted parameters due to various reasons. With these limitations in mind, a handful of key traffic parameters have been identified, based on past

research and the sensitivity study summarized in this report, to be the most important weather-impacted parameters, in terms of their impact on MOEs. Even when resources and budgets are tight, these CORSIM parameters at a minimum should be altered to appropriate values when modeling weather events:

- Mean Free Flow Speed (freeways and arterials),

- Car Following Sensitivity Multiplier (freeways),

- Mean Discharge Headway (signalized intersections),

- Mean Start-Up Delay (signalized intersections), and

- Traffic demand, in terms of reduced demand during more severe weather events (freeways and arterials).

6.4   Step 5 – Model Calibration

Model calibration is an iterative process where the model parameters are altered until the model results (MOEs) adequately match the field measured MOEs. Calibration is needed because often the default parameter values do not result in model MOEs close to those measured in the field. This is especially true when including a weather event in the model, as all microsimulation software packages assume ideal weather conditions in the default values.

Even after adjusting the weather-impacted parameters to appropriate values as described in the previous section, calibration is likely still needed to ensure the best model parameters are used. The *Guidelines for Applying Traffic Microsimulation Modeling Software (18)* recommends a three-step calibration strategy:

1. *Capacity calibration* – an initial calibration of the parameters related to capacity.

2. *Route choice calibration* – a calibration of the traffic demand and route choice parameters to better match volumes measured in the field.

3. *System performance calibration* – a final calibration of all parameters affecting the MOEs in order to better match the model-produced and field-measured system performance.

For each step, calibrating the global parameters (parameters that affect the entire microsimulation model) should be done first, while fine-tuning link-specific parameters as necessary should follow.

The key weather-related parameters as identified in the previous section are also the key parameters used to calibrate any CORSIM model, regardless if a weather event is being modeled. Thus, the process for calibrating a model that includes a weather event is not really different than calibrating a generic CORSIM model. Refer to the simulation guidelines (*18*) for more detail on the calibration process.

Overall, this section highlights the need to measure MOEs in the field, as there would be no basis to calibrate to if field MOEs were not measured. When including a weather event in the microsimulation model, the best way to calibrate such a model would be to collect field MOEs during the weather event being modeled. However, as stated previously, this can be a difficult task.

If field MOEs are chosen not to be collected during the modeled weather event, then a secondary method for calibrating the weather-related model is possible. In this method, the first step is to calibrate the model during ideal weather conditions. This would include coding the microsimulation model for ideal weather and then calibrating the model to field MOEs collected during ideal weather. After developing a calibrated ideal-weather model, then only the weather-related parameters would be adjusted to account for the adverse weather. The weather-related parameters would be adjusted based on the discussion in the previous section (i.e., adjustments based on field data, then past research, and then finally engineering judgment). While such an approach would not produce a model specifically calibrated to the weather event, it would at least produce a reasonably adequate adverse-weather model because it was already calibrated to ideal weather and only a few parameters were adjusted thereafter.

7 Future Research - Modeling Improvements and Case Studies

This section stresses the need for future research in the area of modeling driving behaviors under adverse weather condition. Specifically, CORSIM enhancements and suggested corrections are indicated. A proposed architecture for a weather and traffic data collection system is described. This proposed system is portable and low in cost. A set of proposed CORSIM adverse weather condition case studies are provided for traffic engineer use. Based on these cases, weather-responsive traffic signal control strategies are showcased. Finally, a set of proposed traffic engineer utilities for modeling adverse weather conditions using CORSIM are described.

7.1 Future Research Needs

The study indicated that driver behavior was the weakest link in simulating adverse weather conditions in the simulation models. Driver behavior under different adverse weather conditions is extremely hard to understand and model for many reasons. First of all, it seems driver behavior is location sensitive. For example, driver behavior in snow in Florida is quit different than in Idaho. Second, different adverse weather conditions affect traffic differently (e.g. fog vs. snow). Third, data collection for all weather conditions is difficult, costly and time consuming. Fourth, vehicle performance usually degrades during adverse weather conditions. Drivers usually understand this and react to the conditions with more cautious driving. However, some drivers may underestimate the conditions, and some driver may overreact to conditions. This is what is called driver's perception about the vehicle's performance. Finally, there are about ten types of adverse weather conditions with various severities and endless combination of those conditions and severities, categorizing those combinations and how to best relate those parameters to CORSIM parameters presents a challenge.

Our experience and observations of driving in adverse weather conditions indicates that drivers do drive more cautiously in those conditions, implying more conservative driver behavior. However, there are always a few drivers who drive aggressively, regardless of the weather conditions, making it difficult for other drivers. Based on the sensitivity study, car-following models show potential in modeling all weather conditions, yet improvements and further calibration is needed.

For lane changes, it is much more complicated than with car following. First of all, during some adverse weather conditions, lane markers are not always visible and drivers may drive on some portion of two lanes (i.e., 1.5 lanes, or 2.4 lanes). Current link-based simulations may not be able to handle this behavior, or handle it poorly. Some other factors that might affect lane changing behaviors include lane blockages and narrow shoulders.

7.2 CORSIM Enhancements for Improved Modeling of Adverse Weather Conditions

7.2.1 Separation of Free Flow Speed and Maximum Speed

Under adverse weather conditions, drivers may not drive as fast as under ideal weather conditions. In order to model the changes in weather conditions (e.g. sight distance reduction in fog), in the current version of CORSIM, users need to adjust the free flow speed to slow vehicles down. Keep in mind, delay and other MOEs are calculated according to the free flow speed. Therefore, a reduction in free flow speed reduces the delay and causes undesirable MOE values.

Changes to CORSIM must be made to accommodate this requirement. These changes include:

- A check on all free flow speeds in CORSIM.

- Keep free flow speed in the MOE calculations.

- Use maximum speed for the vehicle movement logic instead of free flow speed. The maximum speed is adjusted automatically (see below) and could be overridden by users.

Adding this feature in CORSIM will require a one-week effort for modeling, programming, and testing.

7.2.2 Inadequate Description of Road Geometry

In civil engineering, a roadway is represented in 3-D profiles, consisting of sight distance elements, vertical alignment elements, horizontal alignment elements, and cross section elements. However, the CORSIM model utilizes only a link length and a FRESIM grade. Other elements are totally ignored. This not only makes modeling some adverse weather conditions inadequate, but also makes TRAFVU displays unpleasant. The minimum elements needed in CORSIM, to adequately model adverse weather conditions, are listed in the following sections.

7.2.2.1 Sight Distance

Sight distance changes under most adverse weather conditions. Without sight distance representation, free flow speed must be manually adjusted to compensate for the reduction in the sight distance.

More importantly, adding decision sight distance and a safe speed to the CORSIM parameters would help in the modeling of adverse weather conditions in CORSIM. Decision sight distance is defined by the Green Book (*16*).

> "The distance required for a driver to detect an unexpected or otherwise difficult-to-perceive information source or hazard in a roadway environment that may be visually cluttered, recognize the hazard or its potential threat, select an appropriate speed and path and initiate and complete the required safety maneuver safely and efficiently".

Unlike stop sight distance, requiring the vehicle to come to a complete stop, decision sight distance can guarantee a safe maximum driving speed. This safe maximum driving speed allows drivers to see an obstacle, sign, or pavement marking clearly, and allows drivers to adapt their driving behavior for maneuvering in snow, fog, and rain. Therefore, allowing a maximum speed to be deduced from the decision sight distance and the safe speed.

Adding this feature in CORSIM will require a one-week effort for modeling, programming, and testing.

7.2.2.2 Horizontal Alignment

A horizontal alignment consists of a straight line, a curve, and a transit curve. The transit curve connects the straight line and the curve. In freeways and higher speed roadways, there is a superelevation established to balance the centrifugal force due to the curvature. The value of the superelevation is determined by the maximum speed allowed on the curve, side friction factor, and the curvature.

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During adverse weather conditions, the side friction factor changes. Because of this change the allowable maximum speed needs to change as well.

Adding this feature in CORSIM will require a one and a half week effort for modeling, programming, and testing.

7.2.2.3 Vertical Alignment

The most important element in vertical alignment is grade. Although grade is integrated in the FRESIM model, it is not considered in the NETSIM model. CORSIM should adjust vehicle acceleration and deceleration rates according to the grade. During weather conditions, the grade, reduced sight distanced, and reduced friction should be used to adjust the allowable speed.

Adding this feature in CORSIM will require a one-week effort for modeling, programming, and testing.

7.2.2.4 Elements in Cross Sections

There are two elements in cross sections, shoulder and lane width, that affect traffic simulation. Currently CORSIM does not model them. Without adequate shoulder, a driver may slow down. Under some adverse weather conditions, the shoulder becomes narrow or disappears. When the lane width becomes partially blocked by snow, a driver may react with more caution and slow down. In a multilane section of road, when a portion of a lane becomes unavailable, driver behavior also changes. These elements need to be added to CORSIM.

Further investigation is still needed to determine how this feature should be modeled and how much it would cost to implement.

7.2.3 Driving Behavior

In CORSIM, users cannot control the percentages of a driver type. The percentage of driver type becomes important when modeling adverse weather conditions, because a driver's type may change due to driver behavior changes.

CORSIM driver behavior does not respond to traffic volume. A utility function should be established to generate a multiplier that will apply to some of the driving behavior parameters (car-following and lane-changing).

Some of CORSIM's driver behaviors are associated with driver types. When calibrating parameters, determining which type of driver resides in a particular car is difficult. It is recommended to change the CORSIM model to use a distribution of Car Following Sensitivity Factors, rather than a multiplier.

The Pitt Car Following Constant currently allows values to vary from 3 to 10. The default value is 10 which did not allow changes to test more conservative behavior for this study. For this study, a modification was made to the CORSIM code to allow larger values to be input for this value. It is recommended to permanently change the CORSIM model to allow larger values for the Pitt Car Following Constant.

7.2.4 Global (Network-wide) Parameters and Link Specified Parameters

During the sensitivity study, it became apparent that currently some parameters are network-wide and all links have to use uniform parameters. With the new capability to model large

networks in CORSIM, it may be beneficial to have certain parameters associated with each individual link. These parameters are:

FRESIM

- Gap Acceptance Parameter
- Lag Acceleration/Deceleration time
- Leader's Maximum Deceleration as Perceived by Follower
- Maximum emergency Deceleration
- Percent Cooperative Drivers
- Time to Complete Lane Change

For car following parameters, it might be better to remove the Car Following Sensitivity Multiplier, adding the following two parameters as link configurable:

- Pitt Car Following Constant
- Car Following Sensitivity Factor

NETSIM

- Discharge Headway Multiplier
- Percent of Drivers who Cooperate with a Lane Changer
- Start-Up Delay Multiplier
- Duration of a Lane Change
- Distribution of Distance to Start to Attempt a Lane Change

7.2.5 Output Processor

Currently in CORSIM, some of the MOEs could not be aggregated. Users should be provided with the means to aggregate each MOE.

7.2.6 Further Sensitivity Study Investigation

There were more than 30 parameters that showed no evidence that they might impact selected MOEs. Further investigation is suggested to determine why these parameters do not impact MOEs and how the model should be modified to work as desired.

FRESIM

- Car Following Sensitivity Factor (changing the mean value impacted the MOEs but just changing the distribution did not)
- Jerk Value
- Advantage Threshold for Discretionary Lane Change
- Discretionary Lane Change Multiplier
- Gap Acceptance Parameter
- Percent Cooperative Drivers

NETSIM

- Driver Type Factor

- Urgency Threshold

- Difference in Maximum and Minimum Deceleration for Mandatory Lane Changes

- Duration of a Lane Change

- Distance Over Which Drivers Perform Lane Change

- Distribution of Distance to Attempt a Lane Change

- Start-Up Delay Multiplier (distribution)

- Discharge Headway Multiplier (distribution)

In addition to these parameters, some other parameters did not produce anticipated trends in the MOEs, and further investigation is needed for these parameters as well. Although it is not expected there will be practical use for these parameters, the investigation will increase model fidelity. These parameters are:

FRESIM

- Maximum Emergency Deceleration Rate

- Leader's Maximum Deceleration Rate as Perceived by Follower

- Anticipatory Lane Change Distance

- Anticipatory Lane Change Speed

NETSIM

- Headway at Which All Vehicles Attempt Lane Change

- Headway at Which No Vehicles Attempt Lane Change

7.3   Weather and Traffic Data Collection

As a part of the TReL upgrade plan, a portable weather and traffic data collection system, as shown in Figure 8 is proposed. The characteristics of the system include the following:

- Inexpensive

- Unobtrusive

- Indirect connection

- Real-Time collection of state information (detector and signal), and video data
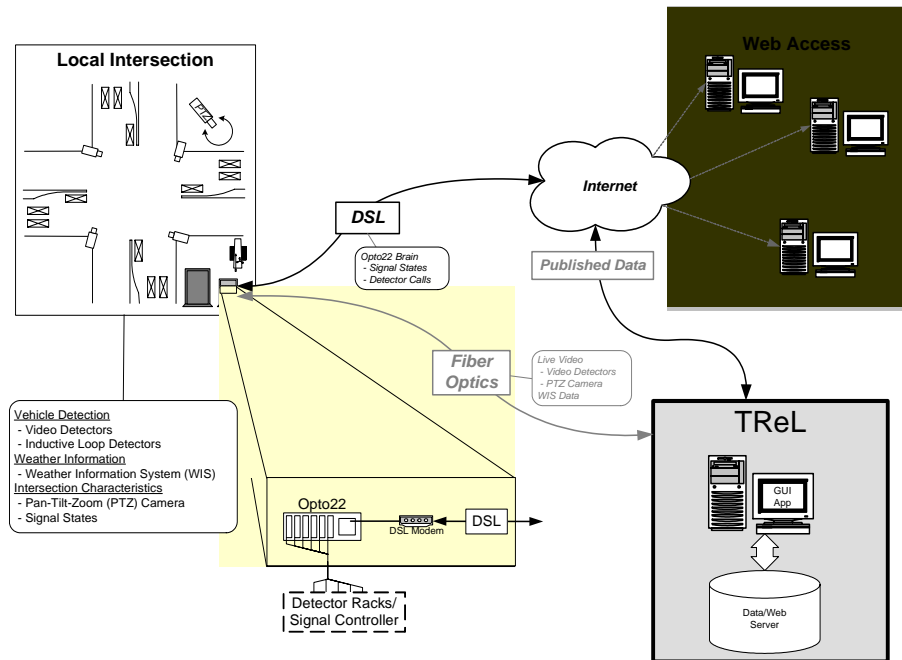
- Portable elements

Figure 8 Portable Data Collection System

Traffic-related data is provided through video. Start-up lost times, queue discharge headways, number of vehicles passing intersection, gap acceptance for permissible left-turners, gaps for right-turners, probability of driver's jump at yellow signals, and turning speeds data is collected via the video for passenger cars and large size trucks.

In addition to traffic data, the weather station could be configured to provide data on precipitation, wind speed, visibility, air temperature, pavement surface temperature, relative humidity, rainfall accumulation rate, snow, and ice accumulation, etc.

7.4   CORSIM Simulation Case Studies

Although it has been concluded that CORSIM is valid in modeling traffic under adverse weather conditions there are only a few applications of simulation under adverse weather conditions available. It is recommended that several adverse weather condition case studies be conducted at the TReL. The objective of these case studies is to calibrate CORSIM using field traffic conditions under adverse weather conditions.

The case studies involve a freeway weaving section, a diamond interchange, and two corridors of arterials with pretimed and coordinated traffic signal control, respectively. These case studies will follow the steps found in the guidelines in Section 6 and show how these guidelines may be applied.

The following field sites were selected:

- 123 at McLean downtown
- Diamond interchange at I-495/Hwy 193

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These sites were selected to minimize the data collection efforts. Weather conditions will be collected at an existing weather station, at the traffic signal inside TFHRC. This weather station is located very close to the selected two sites.

7.5   Weather-Responsive Traffic Signal Control Strategies Case Studies (Showcase)

The objective of the showcase is to demonstrate the benefits of weather-responsive traffic signal timing strategies to the traffic engineer and public.

The cases and the calibrated CORSIM scenarios under various adverse weather conditions described in Section 7.4 will be used in the showcase. With the different weather events, the traffic signal control strategies will be modified to respond to the changes in the weather conditions. TRANSYT-7F, Passer IV and Synchro will be used to aide in the development of a new control strategy. The benefit of a new control strategy is easily demonstrated through simulation of the new and original control strategies.

VDOT is currently coordinating with the TReL to showcase the benefits of the hardware in-the-loop simulation application in traffic signal timing on a selected interchange. If the strategies are proven to be successful in the simulation and there is funding available, field tests of different control strategies may be conducted after VDOT implements the new strategies.

For freeways, a calibration study will be performed to see if decreasing the speed limit under adverse weather conditions will reduce delays. The VMS could be used for speed control.

7.6   Sensitivity Study and Calibration Utilities

Sensitivity study and calibration utilities will benefit CORSIM users and researchers. These utilities will provide the guidance and the tools for conducting sensitivity studies and calibrations. The tools used in this analysis would make a good starting point for a sensitivity study utility. The addition of a graphical user interface would make it user-friendly. A calibration tool could also be added.

The effort for producing these tools needs further investigation.

7.7   Summary

Research in modeling driver behaviors under adverse weather conditions will boost simulation fidelity. These efforts will not only benefit CORSIM, but also other simulation models. Meanwhile, in the short term, CORSIM could be enhanced as summarized in Table 37.

Table 37. Summaries of CORSIM Enhancements.

CORSIM Enhancements	Solution	Estimated Hours	Comment
Separation of Free Flow Speed and Maximum Speed	TBD	TBD	Requires Implementation and Test Plan (ITP)
Horizontal Alignment	TBD	TBD	Requires Implementation and Test Plan (ITP)
Grade	TBD	TBD	Requires Implementation and Test Plan (ITP)
Decision Sight Distance and Safe Speed	TBD	TBD	Requires Implementation and Test Plan (ITP)
Shoulder	TBD	TBD	Requires Implementation and Test Plan (ITP)
Lane Width	TBD	TBD	Requires Implementation and Test Plan (ITP)
Driving Behavior	TBD	TBD	Requires Implementation and Test Plan (ITP)
Global Parameter and Link Specified Parameters	TBD	TBD	Requires Implementation and Test Plan (ITP)
Output Processor	TBD	TBD	Requires Implementation and Test Plan (ITP)
Further Investigation	TBD	TBD	Requires Implementation and Test Plan (ITP)

In addition to these enhancements, the following features are proposed.

- A weather and traffic data collection system should be designed, developed, and installed at the TReL (refer to Section 7.3).

- Calibration case studies and weather-responsive traffic signal control strategies should be created to help users understand how to model adverse weather conditions in CORSIM (refer to Section 7.4 and Section 7.5).

- Provide the traffic engineer utilities to model adverse weather condition using CORSIM (refer to Section 7.6).

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